

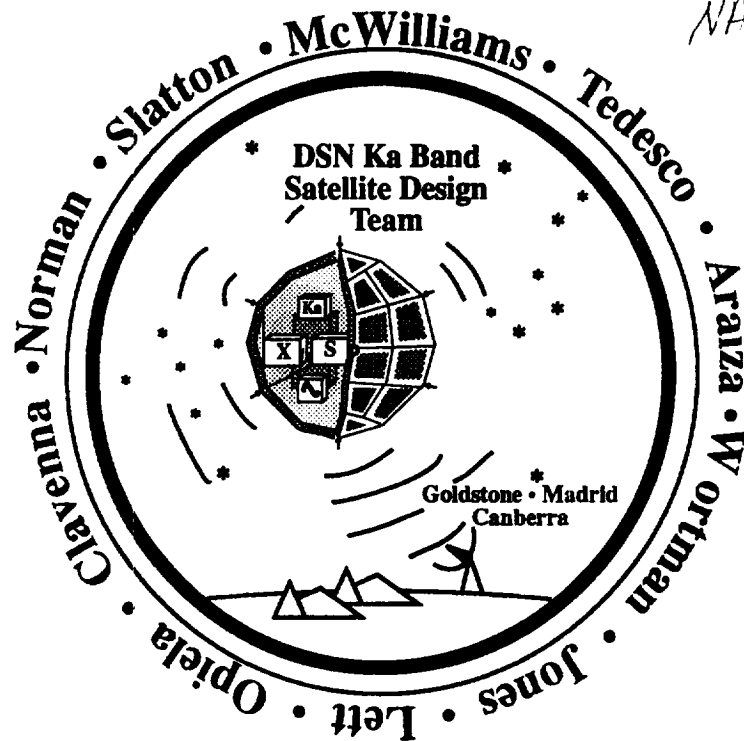
# A Small Satellite Design for Deep Space Network Testing and Training

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DESIGN FOR DEEP SPACE NETWORK  
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## *Mockingbird Designs*

## The University of Texas at Austin Department of Aerospace Engineering

# **Final Design Report**

## **A SMALL SATELLITE DESIGN FOR DEEP SPACE NETWORK TESTING AND TRAINING**

Submitted to

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## **Abstract**

With the continuing exploration of the Solar System and the re-emphasis on Earth focused missions, the need for faster data transmission rates has grown. Ka-Band could allow a higher data delivery rate over the current X-Band, however the adverse effects of the Earth's atmosphere on Ka are as yet unknown. The Deep Space Network and Jet Propulsion Lab have proposed to launch a small satellite that would simultaneously transmit X and Ka signals to test the viability of switching to Ka-Band. The Mockingbird Design Team at the University of Texas at Austin applied small satellite design principles to achieve this objective. The Mockingbird design, named BATSAT, incorporates simple, low-cost systems designed for university production and testing. The BATSAT satellite is a 0.64 m diameter, spherical panelled satellite, mounted with solar cells and omni-directional antennae. The antennae configuration negates the need for active attitude control or spin stabilization. The space-frame truss structure was designed for 11 g launch loads while allowing for easy construction and solar-panel mounting. The communication system transmits at 1 mW by carrying the required Ka and X-Band transmitters, as well as an S band transmitter used for DSN training. The power system provides the 8.6 W maximum power requirements via silicon solar arrays and nickel-cadmium batteries. The BATSAT satellite will be lofted into an 1163 km, 70° orbit by the Pegasus launch system. This orbit fulfills DSN dish slew rate requirements while keeping the satellite out of the heaviest regions of the Van Allen radiation belts. Each of the three DSN stations capable of receiving Ka-Band (Goldstone, Canberra, and Madrid) will have an average of 85 minutes of view-time per day over the satellites ten year design life. Mockingbird Designs hopes that its small satellite design will not only be applicable to this specific mission scenario, but that it could easily be modified for instrument capability for university, government, and/or commercial research.

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## **EXECUTIVE SUMMARY**

Mankind's quest for knowledge of space has led scientists to loft expensive, complex space probes that gather a multitude of data. Current spacecraft can gather more data than their communication system can transmit during limited transmit times. In order to increase efficiency as well as the amount of data a satellite can retrieve, faster data transmission methods must be found. The fastest data transmission rates now occur over X-band. However, a debate by scientists currently focuses on whether NASA should switch to another radio frequency, like Ka-Band, or if they should move on to a more advanced scheme such as laser communication. Mockingbird Designs hopes to aid the debate by studying Ka transmissions. Although the Ka-Band could offer higher data transmission rates, the effect of the atmosphere on the signal is unknown. Therefore Mockingbird designed and plans to produce a small satellite, named BATSAT, that will transmit a test signal over both Ka and X bands to study atmospheric signal attenuations.

The BATSAT satellite incorporates small satellite design principles to provide a simple, low-cost design ideal for university production and testing. The satellite is an 0.64 m diameter space-frame truss structure built of 6061-T6 aluminum truss members. The skin panels will be built of a honeycomb sandwich material, which will be mounted to the outer truss structure using locking bolts. In lieu of an axial strut to support launch loads, an inner strut configuration will provide stiffness. The inner strut design also provides more space inside the spacecraft for component placement. The components will be placed in an insulated disk that will be isolated from the structure using nylon cords. Using a NASTRAN

structural model, Mockingbird found that the spacecraft has a large structural design margin while maintaining a low mass. This could be very beneficial if one wished to increase the component mass by adding scientific instruments.

The communication system includes Ka and X-Band transmitters that are used to carry the test signal. Mockingbird also plans to include an S band transmitter that will be used to help train DSN personnel. By purposely turning certain antennae off, DSN trainees could determine the attitude motion of the satellite via blinking techniques. The spacecraft will transmit the 1 mW test signal over four omni-directional antennae provided for each band. The increase in signal interference due to these antennae can be compensated for using filter techniques available at DSN, but most importantly these effects are distinguishable from atmospheric effects. Commands will be up-linked via an X-Band transponder and a step logic circuit will change the spacecraft configuration for different subsystems. Also, to insure that the satellite can always be in a known state, a reset command was designed to return the satellite to an initial state.

Thermal control is often a problem for small satellites. To compensate, Mockingbird Designs cold biased the BATSAT satellite. The outer surface will be covered with solar arrays, and all remaining surfaces will be painted white. This prevents the satellite from exceeding hot temperature limits. To prevent certain satellite components from getting to cold, small thermal strip heaters with a thermostat will be used to heat up components. Since all components will be placed in a circular disk, components can also be warmed via thermal blankets. Also, the circular disk can be radiation hardened to increase satellite reliability.

When the satellite is transmitting over both X and Ka-Bands with heaters on, it will need 8.6 W of power. This maximum power requirement will be fulfilled using silicon solar arrays and nickel-cadmium batteries. The solar arrays will be surface mounted to the honeycomb skin structure to offer omni-directional solar flux coverage. A peak power tracker will be used to smooth out the power from the arrays. Both the solar arrays and the batteries are designed for a 10 year lifetime. Four batteries will be used: one for the first five years, one for the second five years, and two redundant batteries.

The BATSAT satellite will be lofted into an 1163 km, 70° orbit by the Pegasus launch system. This orbit fulfills the DSN dish slew rate requirement of .4 deg/s while also keeping the satellite out of the heaviest regions of the Van Allen radiation belts. Currently, only the Goldstone, California DSN dish can receive in Ka-Band, but the Canberra, Australia and the Madrid, Spain dishes will soon be upgraded. Each of the three DSN stations capable of receiving Ka-Band (Goldstone, Canberra, and Madrid) will have an average of 85 minutes of view-time per day. A seven day repeating groundtrack will allow for easy planning and view time estimates. The Pegasus launch system by Orbital Sciences Corporation will provide the launch services for BATSAT. Pegasus offers the lowest priced commercial launch option while providing many performance options that decrease satellite complexity. While the Pegasus system is relatively cheap (around \$9 million), Mockingbird Designs is researching cheaper options such as shared launch and military surplus.

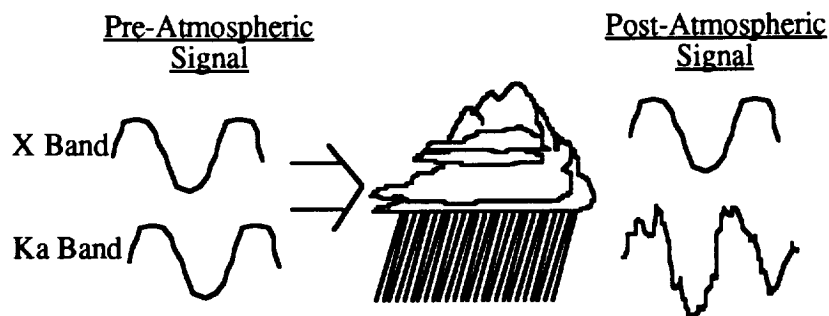
The current BATSAT design offers an excellent spaced-based platform for testing the merits of Ka-Band transmissions. The satellite fulfills the mission goals while keeping complexity and costs down.

However, the most important aspect of the BATSAT satellite is its receptiveness to university design. By using students to design, fabricate, and test the satellite structure, costs can be kept to a bare minimum. Many of the electronic components have been built by other university groups and can be adapted to the BATSAT design. Even though this satellite was designed specifically for the DSN/JPL testing project, the small satellite can easily be modified to carry scientific instruments. Mockingbird hopes that other missions will wish to use the BATSAT design for their small satellite applications.

## 1.0 INTRODUCTION

### 1.1 Background and Mission Statement

In the search for higher data transmission rates for spacecraft, the Deep Space Network (DSN) and Jet Propulsion Laboratory (JPL) are investigating the use of alternate radio-frequency bands for satellite communication. The fastest data transmission rates currently available are through X-band, and most space probes communicate over this band. Ka-



**Figure 1.1:** Atmospheric effects on radio transmissions.

band allows for a faster transmission rate, but is more susceptible to atmospheric interference than X-band (see Figure 1.1).

However, the precise effects of the atmosphere (i.e. clouds, rain, air) on Ka transmissions have not yet been characterized, and DSN must study whether the advantage of faster communication through Ka will be offset by signal degradation due to the atmosphere. In order to study this problem, DSN and JPL have proposed deploying a small satellite that would transmit an identical signal over both X and Ka-Bands. Mockingbird Designs has named the satellite project BATSAT. Reflecting on the goals of the DSN and JPL project, the mission statement for the BATSAT is:

- To provide simultaneous X and Ka-Band transmissions to the three 34-meter, high-efficiency DSN receivers to study the effects of the atmosphere on Ka-Band.

With simultaneous X and Ka-Band transmission, the atmospheric interference could be characterized by studying the comparative variations in the signals.

A secondary goal for the satellite is to aid in training new DSN personnel. By adding an S-Band transmitter, ground station trainees could use Doppler shift and blinking techniques on S-Band to determine the attitude and motion of the satellite. With 1 mW transmission power, BATSAT would look like a deep space probe and trainees could practice acquisition and attitude determination skills.

## **1.2 Project Scope and Goals**

At the start of the project, the Mockingbird Design team set several goals to define the scope of the project. Mockingbird Designs is not the first design team to look at this mission. The Student Undergraduate Research Fellowship (SURF) presented their mission design in the SURFSAT project at California Institute of Technology. Mockingbird did not want to repeat or replace the work done by SURFSAT, but wanted to improve the design and offer different insight into the problem.

The primary goal of the project was to design the best space-based platform for studying Ka transmissions through the atmosphere. Other non-space based methods may be cheaper, but would not provide the wealth

of data that a space platform will yield. Mockingbird also wanted to design a simple spacecraft using existing technology. Since the mission is very simple, there is no need for complex equipment or new technology. Both of these goals lead to the last, and perhaps most important goal: To design a spacecraft simple enough for college production. Throughout the design process, every decision was subject to this last consideration. The main focus of the team was to ensure that the design was simple enough for production in student materials labs and testing in university labs.

### **1.3 Spacecraft Requirements**

Due to the scientific nature of the mission, the spacecraft must fulfill specific requirements. JPL established several requirements to guarantee that the scientific goals are satisfied. These requirements are as follows:

- Simultaneous transmission of X and Ka-Band
- 2-year minimum lifetime to characterize long term weather effects
- Low-cost, simple design.

In addition, the Deep Space Network also set several requirements to support its project objectives and limitations. These criteria include the following:

- A maximum dish slew rate of  $0.4^{\circ}/\text{sec}$
- Signal power of 1 mW radiated by antenna
- S transmissions for training and research.

The BATSAT satellite must satisfy these criteria in order to fulfill its mission goals.

#### **1.4 Mockingbird Performance Goals**

Although JPL and the DSN set performance goals to ensure mission success, Mockingbird established its own performance criteria to improve the mission while incurring negligible cost increases. Specifically, Mockingbird designed the BATSAT spacecraft around several performance characteristics:

- A ten-year lifetime constrained by solar array degradation and nickel cadmium battery lifetime
- A seven-day repeating ground track, with an average view time of about 85 minutes per day per station
- Attitude determination using antennae interference patterns and blinking techniques.

Mockingbird has designed BATSAT to exceed JPL and DSN requirements, and to provide the best science data possible.



Mockingbird has also designed BATSAT to provide several enhanced performance options to accommodate JPL and DSN project modifications. Specifically, these optional design features are as follows:

- Passive instrument capability
- Options for multiple satellite launch to provide redundancy and to reduce mission costs
- A gravity gradient optional design for laser communication testing.

Mockingbird hopes that these options will allow JPL and DSN to vary the design as the need arises for greater scientific return at a lower cost. Also, if this design is built by university production, these options could easily be added.

## **1.5 Concerns**

Currently, Mockingbird's biggest concern is reducing launch costs. Options include using a multiple launch system on a booster such as Ariane or Pegasus. A multiple launch would likely involve sharing the booster with one or two other small satellite payloads. The ORBCOMM satellites being launched into constellation by the Pegasus system could offer an attractive option. Since the orbit of BATSAT is critical to the mission design, these other satellites on a shared launch would need to have orbits above 1095 km altitude to satisfy the slew rate constraint. Another major design concern is satellite radiation hardening. Even though BATSAT's orbit will be well below the intense inner Van Allen Radiation Belt, some

hardening will probably be needed to increase satellite lifetime. Radiation hardening analysis will be performed upon receipt of electronics hardware specifications.

The current satellite design is vulnerable to single point hardware failures that would destroy the mission. However, redundancy in hardware increases production costs and control complexity. Therefore redundancy will be accomplished through multiple satellites instead of multiple subsystems.

The current BATSAT design satisfies all criteria and requirements for the mission. Mockingbird Designs has confronted many technical hurdles to keep the design as inexpensive and reliable as possible. Mockingbird believes that the BATSAT project also fulfills the project goals of being simple and inexpensive. The design team feels that the University of Texas possesses all of the tools necessary to construct and test the satellite, and should continue design and construction.

## **2.0 STRUCTURES**

### **2.1 Introduction**

To design an appropriate structure for the BATSAT mission, three broad requirements were specified. The first requirement that the BATSAT structure must fulfill is to provide a physical platform for the payload. This requires that the structure fit inside the payload envelope of the Pegasus launch vehicle, provide enough volume to hold the internal components, and provide external mounts for solar cell arrays and antennae.

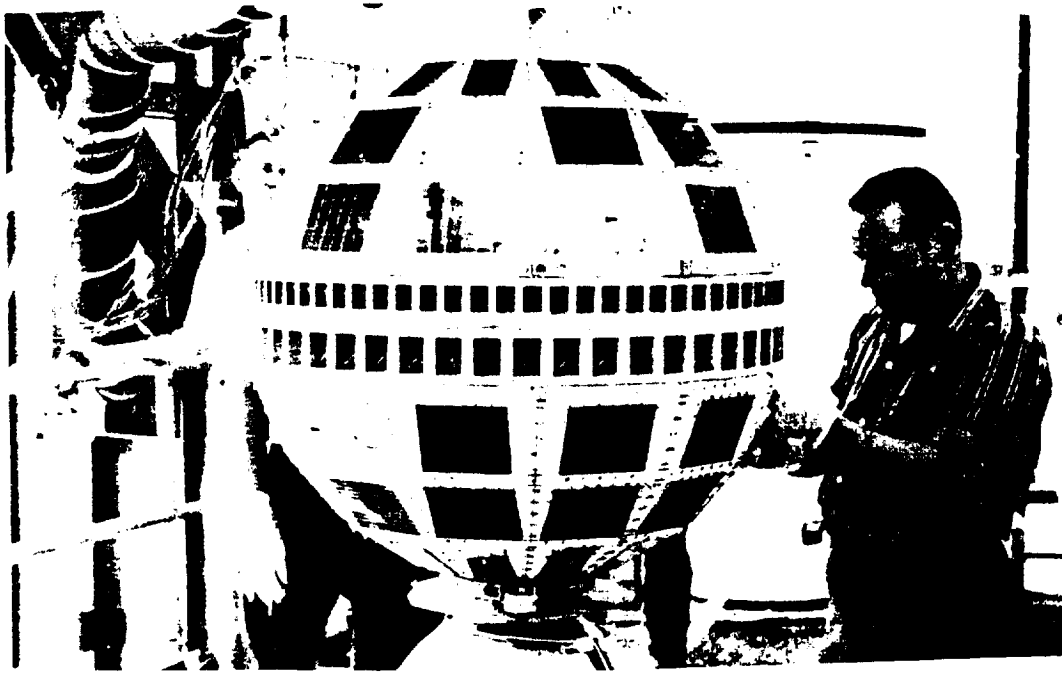
The second requirement is that the structure be able to survive the Pegasus launch environment. The structure will experience significant accelerations along both the rocket center-line and normal to the center-line. In addition, the BATSAT structure must have a fundamental frequency large enough so as not to resonate at launch vibration frequencies.

Finally, the BATSAT structure must have a suitable mass distribution. The launch vehicle manufacturer has constraints on the center of gravity location and how far it can move from its original position on the rocket center-line. Any structural deflections must be small enough not to violate the constraints on the center of gravity. Also, since BATSAT will be spin stabilized, the maximum moment of inertia must occur about the spin axis.

## 2.2 Structural Design

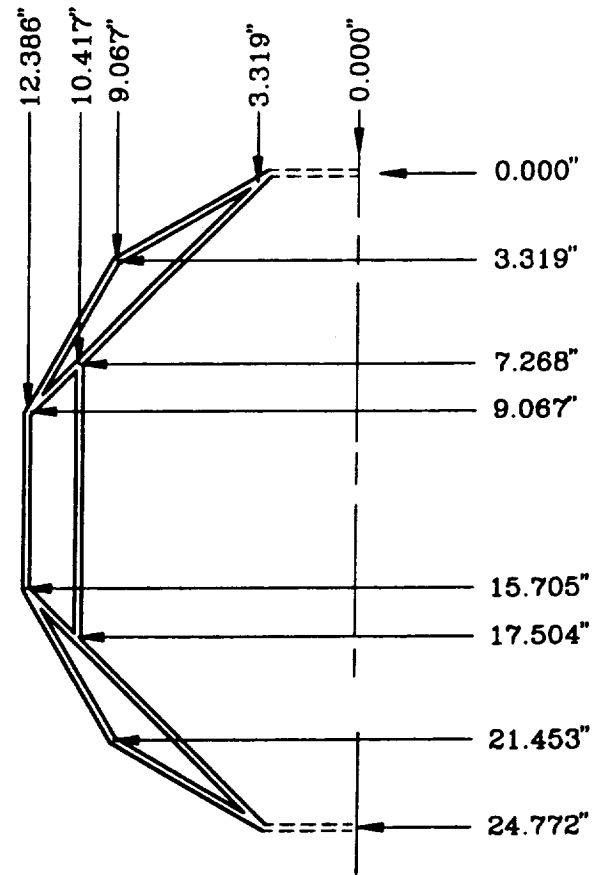
Because BATSAT should have a simple structure, a spherical design was chosen for the spacecraft. A spherical design allows for the uniform placement of antennae and solar cells over the surface, avoiding the need for active attitude control. In an effort to avoid potential pitfalls in the structural design process, the designs of similar spacecraft were studied.

The design of BATSAT's structure was an iterative process. During the conceptual design phase, a gravity gradient design was weighed against the spherical structure. Mockingbird decided that the gravity gradient design was overly complex, thus reducing mission reliability and increasing development costs. However, Mockingbird has kept the gravity gradient design as an alternative if a satellite pointing became a necessity. Once the spherical structure was selected as the primary design choice, study of the internal support structure began. The first design considered was similar to that of the Philco Corporation's Courier satellite [Courier]. This design consisted of a central axial member that was connected via pinned rods to a large equatorial support ring. Mockingbird concluded that such a design would not provide adequate support to the solar-cell-covered skin, possibly leading to local buckling of the skin during launch. The central axial member design was discarded in favor of a faceted-sphere frame design similar to that of AT&T Bell Laboratory's Telstar 1 [Brown: 245, 295], as shown in Figure 2.1. The faceted-sphere structure was selected as the primary BATSAT structural design. It provides well-supported mounting locations for the skin panels, and provides an internal cavity in which an instrument package can be placed. This design allows for easy mounting of solar panels, which greatly simplifies the construction process.

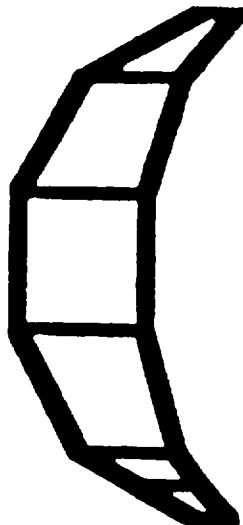


**Figure 2.1:** Bell's Telstar satellite.

The final BATSAT structural design is a variant of the Telstar 1 structure. The internal support is provided by an aluminum 6061-T6 space frame shown in Figure 2.2. The frame consists of twelve sections placed at  $30^\circ$  increments about the structure center-line (see Figure 2.2). The frame consists of 0.25" x 1.00" channel members welded together. Each frame section is connected to adjacent sections by circumferential support members (Figure 2.3). The circumferential members are aluminum 6061-T6 members with solid 0.125" x 1.00" cross sections. There are two sets of these members at each bend in the outer frame, and a single set at the launch ring interface.



**Figure 2.2:** CAD Drawing of frame.



**Figure 2.3:** Picture of truss structure.

The structure has an overall diameter of 0.64 meters. Once the frame is constructed, skin panels, consisting of honeycomb material sandwiched between aluminum 6061-T6 plates, are attached to the frame via locking bolts. The use of locking bolts ensures that skin panels can be removed during assembly if necessary, but that thermal cycling will not cause slop once BATSAT is in orbit. Compliant washers will be placed between the frame and the skin panels to protect the solar cells from the launch vibrations. The truss structure will be built in two hemispherical sections to allow easy access to components during construction.

### 2.3 Initial Structural Modeling

To verify the BATSAT structural design, a NASTRAN computer model was developed (see Appendix A for a selected listing of the NASTRAN model). Table 2.1 lists the simplifications to the actual BATSAT design that were used to create the NASTRAN model.

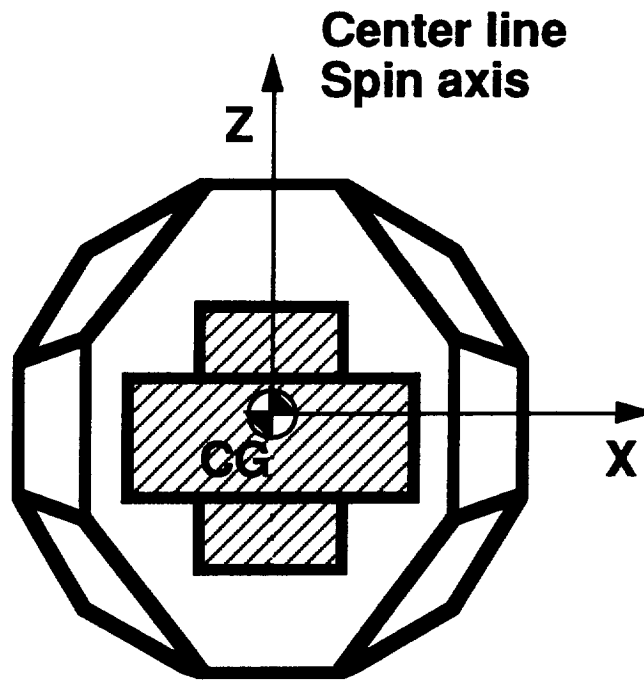
**Table 2.1: NASTRAN Model Simplifications**

| Item                                   | BATSAT Structure                           | NASTRAN Model                            |
|--|--|--|
| Frame element cross sections           | 0.25" x 1.00" channel                      | 0.25" x 0.25" solid                      |
| Circumferencial element cross sections | 0.125" x 1.00" solid two sets at each bend | 0.25" x 1.00" solid one set at each bend |
| Skin panels                            | Honeycomb and aluminum sheets              | Single aluminum sheets 0.12" thick       |

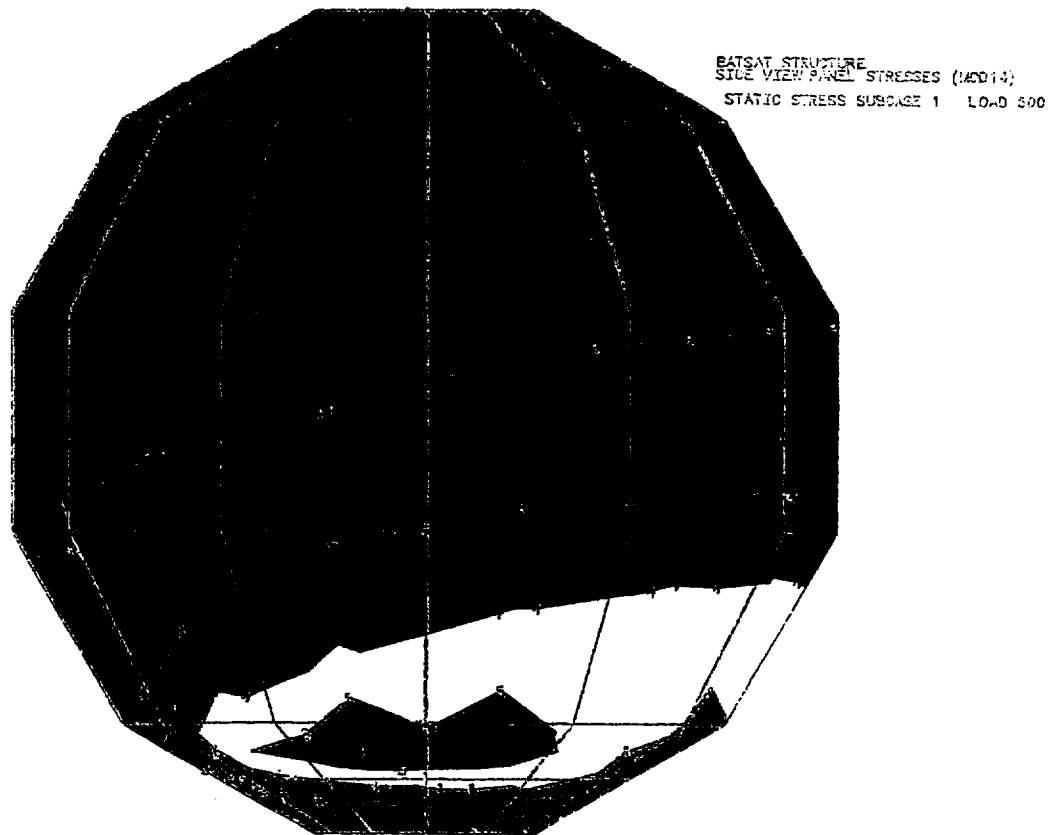
The NASTRAN model was used to determine the structure's fundamental frequency and its response to the maximum launch accelerations. A FORTRAN program named MODIFY was written to generate the grid points for the NASTRAN model (see Appendix A for program listing). Both the NASTRAN code and MODIFY program assume fundamental SI units. The frame and circumferential members were modeled using BAR elements, and the skin panels were modeled using QUAD4 and TRIA3 elements. Translational motion was constrained at the grid points where the launch ring would attach; no other grid points were constrained. The constrained grid points correspond to a launch ring with a 0.315 meter diameter. The actual ring turned out to be 0.245 meters in diameter, but the NASTRAN results should be approximately correct. The fundamental frequency of the BATSAT structure was found by running a separate, but linked NASTRAN program. The structural model was subjected to an 11 g acceleration in the direction of the Pegasus center-line, and a 3.5 g acceleration normal to the center-line. Figure 2.4 shows the spacecraft's z-axis, as well as the component containment structure mounted inside.

After running the NASTRAN model of the BATSAT structure, it was apparent that the structure would satisfy all constraints by several orders of magnitude. The maximum normal stress contours in the skin panels are plotted in Figure 2.5. No detailed analysis on skin panels was carried out due to time constraints. The contour plot was generated to help future Mockingbird engineers focus on high stress areas.





**Figure 2.4:** Z - axis of satellite structure along with component disk.



**Figure 2.5:** Color contour plot showing the relative stresses in the skin elements.

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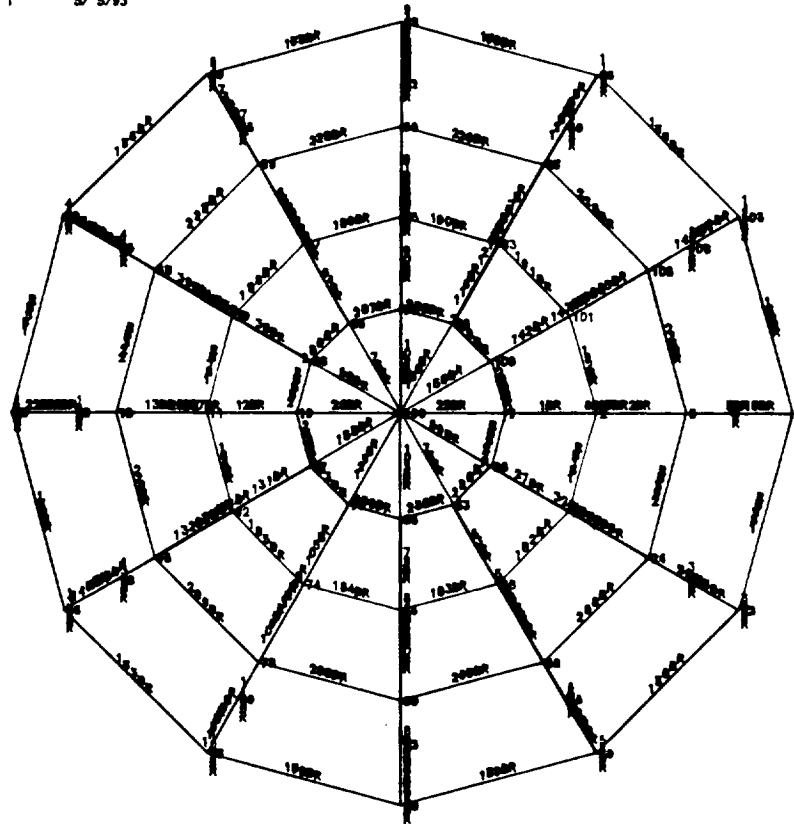


Figure 2.7: Top view of NASTRAN plot.

## 2.4 Structural Integration

To fulfill the BATSAT mission, the structural design was integrated with the communication, power, and spin stabilization requirements. For thermal control reasons, it is desirable to consolidate the electronic instruments into a single instrument package inside the BATSAT frame. Approximately  $0.6 \text{ m}^3$  volume is needed to house the electronic communication and power equipment. Using this volume as a design constraint, the final design provides approximately  $0.63 \text{ m}^3$  of volume for the electronic equipment. Figure 2.4 shows the component disk mounted inside the spacecraft structure. Once the instrument package is completed, it is mounted onto the structure via nylon cords, which will absorb much of the launch vibrations.

## 2.5 Spacecraft Overview

The mass budget for the final design is given in Table 2.2.

**Table 2.2: Mass Budget**

| No.                            | Element          | Comments, Heritage        | Unit Mass | Total Mass      |
|--------------------------------|------------------|---------------------------|-----------|-----------------|
| <b>Communication</b>           |                  |                           |           | <b>4.85 kg</b>  |
| 1                              | Ka Transmitter   | SURFSAT, pre-tested       | 1.00 kg   | 1.00 kg         |
| 1                              | X Transmitter    | SURFSAT, pre-tested       | 0.70 kg   | 0.70 kg         |
| 1                              | S Transmitter    | SURFSAT, pre-tested       | 0.42 kg   | 0.42 kg         |
| 8                              | X Antenna        | SURFSAT, pre-tested       | 0.06 kg   | 0.48 kg         |
| 8                              | Ka Antenna       | SURFSAT, pre-tested       | 0.08 kg   | 0.64 kg         |
| 8                              | S Antenna        | SURFSAT, pre-tested       | 0.08 kg   | 0.64 kg         |
| 0                              | Ku Antenna       | SURFSAT, pre-tested       | 0.10 kg   | 0.00 kg         |
|                                | Cables           |                           | 0.97 kg   | 0.97 kg         |
| <b>Power</b>                   |                  |                           |           | <b>8.07 kg</b>  |
| 1                              | Peak Power trkr. | Off the shelf, space qual | 3.00 kg   | 3.00 kg         |
| 1                              | Solar Array      | Lockheed space qual. Si   | 1.95 kg   | 1.95 kg         |
| 2                              | Ni-Cad Batteries |                           | 1.40 kg   | 2.80 kg         |
|                                | Cables           |                           | 0.32 kg   | 0.32 kg         |
| <b>Thermal &amp; Radiation</b> |                  |                           |           | <b>8.20 kg</b>  |
| 1                              | Blankets         |                           | 3.00 kg   | 3.00 kg         |
| 2                              | Strip Heaters    | Minco                     | 0.10 kg   | 0.20 kg         |
| 1                              | Shielding        |                           | 5.00 kg   | 5.00 kg         |
| <b>Command Sys</b>             |                  |                           |           | <b>2.60 kg</b>  |
| 1                              | X Receiver       | SURFSAT, pre-tested       | 0.60 kg   | 0.60 kg         |
| 1                              | Logic Circuits   |                           | 2.0 kg    | 2.00 kg         |
| <b>Structure</b>               |                  |                           |           | <b>16.60 kg</b> |
| <b>Payload</b>                 |                  |                           |           | <b>0.00 kg</b>  |
| 0                              | Grav Meter       |                           | 10.00 kg  | 0.00 kg         |
| 0                              | Radiation Meter  |                           | 10.00 kg  | 0.00 kg         |
| 0                              | Voltage Meter    |                           | 3.00 kg   | 0.00 kg         |

|        |     |
|--------|-----|
| Margin | 20% |
|--------|-----|

|                |         |
|----------------|---------|
| S/C Dry Weight | 48.4 kg |
| Launch Adapter | 17.0 kg |
| Boosted Weight | 65.4 kg |

|                     |         |
|---------------------|---------|
| Total Launch Mass = | 65.4 kg |
|---------------------|---------|

The masses of the electrical equipment were provided by the SURFSAT team at JPL, and the structure mass was computed by NASTRAN. After adding a 20% contingency factor and accounting for the launch adapter ring, the estimated total boosted mass is 65.4 kg. This mass is well below the Pegasus mass-to-orbit constraint for the BATSAT orbit.

Once the total BATSAT mass was determined, the distribution of that mass had to be specified. Orbital Sciences Corporation (OSC) requires that the payload center-of-gravity not move along the Pegasus' center-line more than 13 mm from its original position, and not more than 6.4 mm normal to the Pegasus' center-line [Pegasus User Guide, 5-10]. The NASTRAN model revealed a maximum structural deflection of 3.3E-5 meters. It is reasonable to conclude that even with relatively flexible nylon attachments, the center of gravity will remain within OSC's constraints.

To ensure stable spin, the maximum moment of inertia must occur about the z-spin axis (Figure 2.4). The maximum moment of inertia of the structure does not occur about the spin axis, but by placing the instruments in disk shaped packages, the maximum moment of inertia was made to occur about the spin axis. These moments of inertia are listed in Table 2.3.

**Table 2.3** Moments of Inertia (kg\*m<sup>2</sup>)

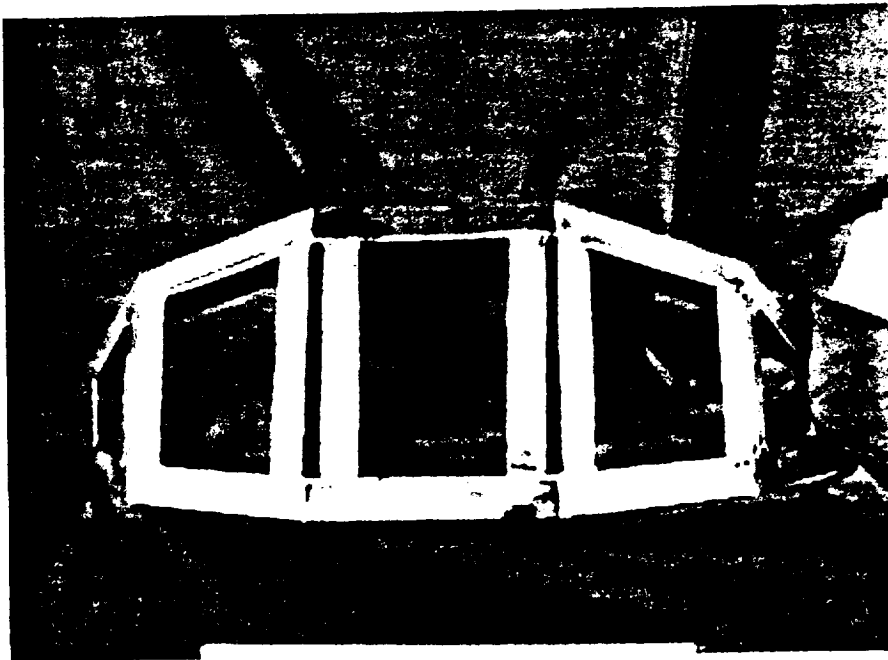
|                 | I <sub>spin axis</sub> | I <sub>lateral axis 1</sub> | I <sub>lateral axis 2</sub> |
|-----------------|------------------------|-----------------------------|-----------------------------|
| Structure       | 1.028                  | 1.118                       | 1.118                       |
| Instrumentation | 0.979                  | 0.559                       | 0.559                       |
| TOTAL           | 2.01                   | 1.68                        | 1.68                        |

During production, the electronic components could be arranged such that

$$I_{\text{lateral axis 1}} \neq I_{\text{lateral axis 2}}$$

so that a marginally stable condition is avoided.

A full-scale segment of the BATSAT structure was manufactured to study possible production methods (see Figure 2.8). Based on this prototype, each of the twelve segments seen in Figure 2.2 will be constructed by welding individual members. A jig would then be constructed to hold these segments while they were joined together by welding the circumferencial members to the frame joints. In this manner, two hemispheres would be built. These two hemispheres would remain separate until the final stages of production to preserve accessibility to the instrument package. Once the hemispheres are joined, the skin panels are bolted onto the frame with locking bolts and compliant washers.



**Figure 2.8:** Welded structure built as production model.

## **2.6 Recommendations**

Mockingbird Designs offers several recommendations can be made for continued work on the BATSAT structure:

- Replace the NASTRAN approximations for member cross sections and skin panel material with the actual final design values (see Table 2.1)
- Study skin panel stresses to check for local buckling and deflections great enough to break the glass covered solar cells mounted on the skin panels
- Model launch vibrations in a dynamic NASTRAN program
- Study manufacturing techniques to improve the manufacturability of the structure.

By continuing on these recommendations, Mockingbird feels that the BATSAT satellite will be an excellent generic small satellite, offering ease of production and low cost.

## **3.0 COMMUNICATION AND POWER DESIGN**

### **3.1 Introduction**

The communication hardware is the scientific payload for BATSAT. The communication power requirements determine the sizing of the power subsystem. If a passive sensor is added to the design, the increase in the power requirement will be minimal. All sizing numbers include a 20% contingency factor. Some of the communication and power hardware require active thermal control, which slightly increased BATSAT's power requirements through small thermal heaters.

### **3.2 Communication Design**

The communication subsystem is described by its hardware and its operation modes. The hardware consists of electronic components, such as transmitters, receivers, and antennae. The operation modes determine which transmitters are on and which antennae are transmitting the signal.

An undergraduate research group at the California Institute of Technology has worked on this project before in the SURFSAT program. They bought and/or made the communication equipment that BATSAT will need. Mockingbird wants to integrate this equipment into the BATSAT design to reduce production costs.

BATSAT can transmit on three radio-frequency bands, Ka, X, and S. Table 3.1 details the communication equipment. The signal-to-noise ratio for all of the communication links is well within tolerance levels. The X-Band command receiver handles the instructions from ground stations.



**Table 3.1: Communication Subsystem Characteristics**

|                             | Downlink<br>Frequency (GHz) | Uplink<br>Frequency (GHz) | Emitted<br>Power (mW) | Signal to Noise<br>Ratio |
|-----------------------------|-----------------------------|---------------------------|-----------------------|--------------------------|
| <b>Transmitters</b>         |                             |                           |                       |                          |
| Ka-Band                     | 31.9096                     | -                         | 1                     | 4 2                      |
| X-Band                      | 8.451                       | -                         | 1                     | 4 3                      |
| S-Band                      | 2.2895                      | -                         | 1                     | 4 4                      |
| <b>Command<br/>Receiver</b> | -                           | 7.19                      | -                     | 2 8                      |

[Source: SURFSAT PDR]

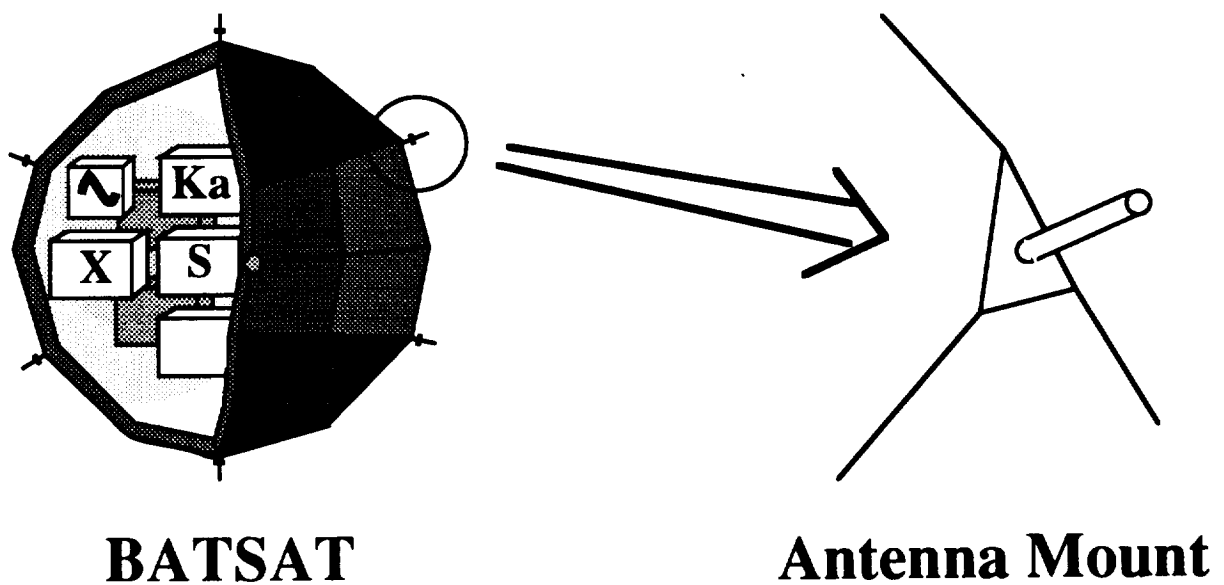
There are four satellite operation modes. In the primary mode, BATSAT will transmit on both X-Band and Ka-Band, using four antennae for each band. There are two S band operation modes. In training mode, BATSAT will transmit in S band with all four antennae. In attitude determination mode, BATSAT will transmit with only one antenna. This will allow DSN personnel to determine the attitude motion of the satellite by measuring the blinking signal. During off mode, the collected solar power will be dedicated to battery recharge and heaters.

### **3.3 Antenna Design**

BATSAT wishes to use the antennae built and tested by the SURFSAT design group. This decision was made to minimize development costs and simplify the design procedure. These antennae meet the mission requirements and are easily integrated into the BATSAT design. Illustrations of two (S and Ka) of the SURFSAT antennae are shown in Appendix B.

BATSAT does not have attitude control therefore it will be subject to perturbations that may cause it to tumble. Consequently, the placement of

the antennae must be such that the signal will be omni-directional. To meet this requirement, BATSAT will need four antennae for each transmitter. These antennae will be placed on the surface of BATSAT, equidistant from one another. The antennae will be mounted at the nodes of intersecting satellite panels. This configuration is illustrated in Figure 3.1. BATSAT has a set of redundant antennas for each transmitter, for a total of 28 antennas on the satellite, including the four X-Band receiving antennae.



**Figure 3.1:** Antenna mounting schematic

An example of the radiation pattern for the omni-directional antenna is seen in Figure 3.2. Because four antennae will be transmitting at the same frequency at once, they will create an interference pattern. The interference pattern can be characterized, allowing an interference filter to be developed [Lundberg]. It is important to note that the interference effects on the signal are distinguishable from the attenuation effects of the atmosphere. Once the filter is designed, the atmospheric effects can be

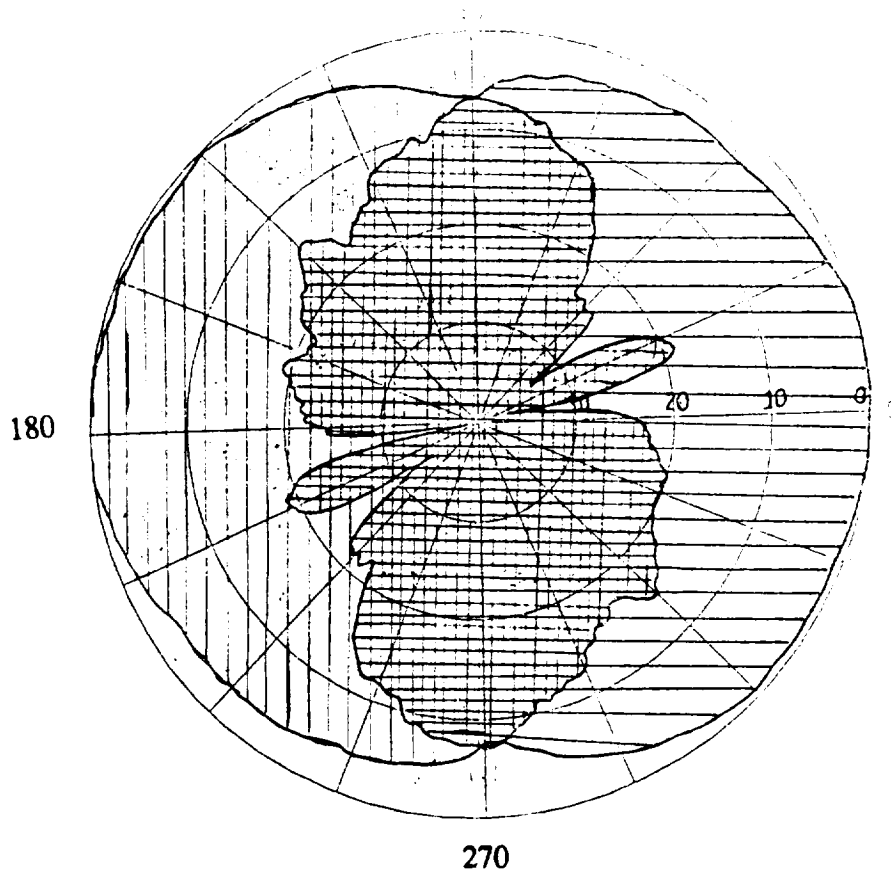
separated and analyzed from the normal signal variations due to the satellite itself.

Currently, the only DSN antenna that can handle Ka-Band is located in Goldstone, California. However, DSN intends to upgrade the stations in Madrid, Spain and Canberra, Australia to provide Ka-Band capability. All three of these high efficiency antennae are 34 m in diameter and have a slew rate of  $0.4^\circ$  per second. The precise locations of the DSN stations are shown in Table 3.2. These antennae are currently used to communicate with deep space probes, such as Ulysses and Galileo, using X-Band frequencies.

**Table 3.2: DSN Station Coordinates**

| <b>DSN Station</b> | <b>Latitude</b>        | <b>Longitude</b>        |
|--------------------|------------------------|-------------------------|
| Canberra           | $35.0^\circ \text{ S}$ | $149.1^\circ \text{ E}$ |
| Goldstone          | $35.4^\circ \text{ N}$ | $116.8^\circ \text{ W}$ |
| Madrid             | $39.5^\circ \text{ N}$ | $3.5^\circ \text{ W}$   |

In order to determine the attitude of the satellite, BATSAT can be commanded to enter attitude determination mode. During this mode, three of the S band antennae will switch off. By analyzing the blinking signal of the single S band transmission, the attitude of the satellite can be determined [Kinmam]. This option will also be useful for training operations at the DSN stations.



**Figure 3.2: S band antenna radiation interference pattern**  
[Source: SURFSAT PDR]

### **3.4 Power System**

The electrical power subsystem comprises three major parts: power generation, distribution, and storage. This subsystem must provide the capability to generate 8.6 W at the end of BATSAT's 10 year lifetime. It will also include the capability to operate during eclipse cycles.

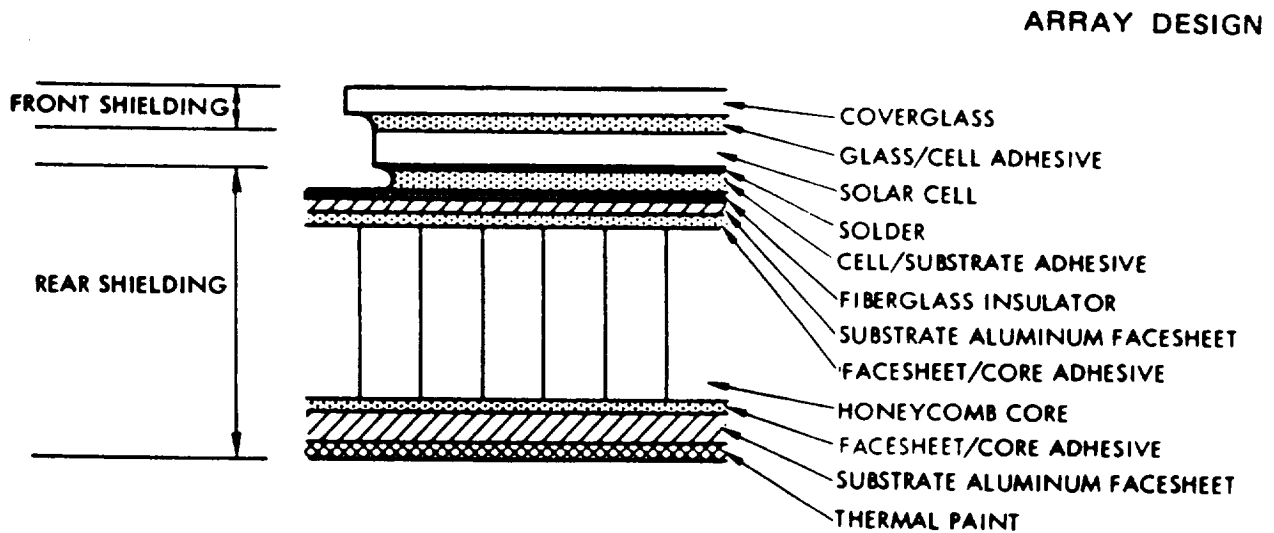
### **3.4.1 Electric Power Generation**

Since the design lifetime of BATSAT is ten years, the satellite will need to generate its own electric power during the mission. Primary, or non-rechargeable, batteries are not a suitable energy source, since the loads would drain the batteries before the end of the mission [Wertz and Larson:402]. Longer-lived sources of electricity include photovoltaic (solar) cells, thermodynamic-cycle engines, radioisotope thermoelectric generators (RTGs), and nuclear reactors. Considering safety, complexity, cost, and power requirements, photovoltaic cells are the most logical choice to provide power for BATSAT.

The primary constraint in sizing a solar array is the power required by the satellite. BATSAT must be able to transmit in one of two modes: X and Ka simultaneously, and S only. Maximum power consumption of the satellite is 8.6W. The solar array is therefore sized to provide 8.6W of power at the end of a ten-year lifetime.

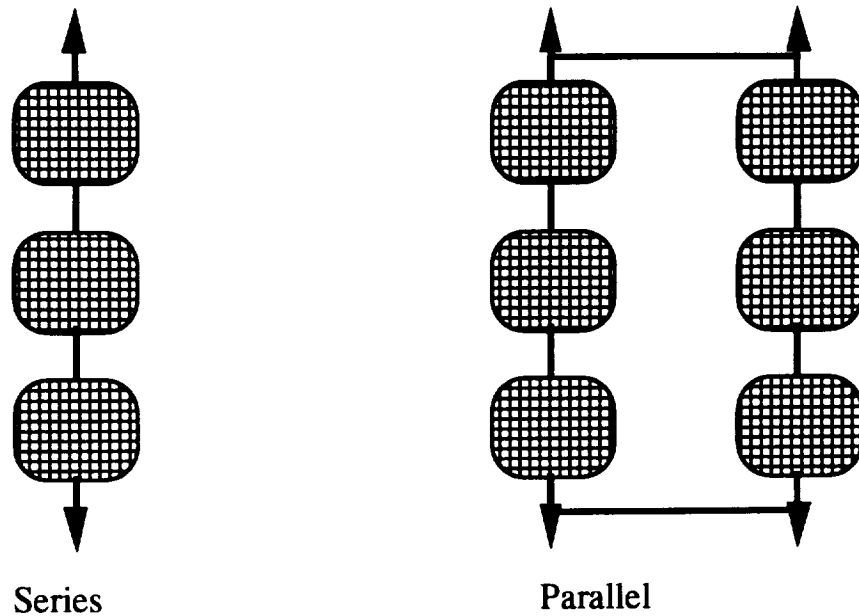
For power collection, BATSAT will have surface-mounted, omnidirectional solar arrays. Flight-qualified solar cells are made from either silicon (Si) or gallium-arsenide (GaAs). Si cells are inexpensive and have been used in space for nearly thirty years. These cells convert about 14% of the incident solar radiation into electricity. GaAs cells are more efficient (18% conversion) and more radiation-resistant than Si cells, but GaAs cells have not been flown extensively. GaAs cells also cost about seven times as much as Si cells [Wertz and Larson:354]. Therefore Silicon cells were chosen as the most cost-effective cell type for the BATSAT mission. Figure 3.3 shows a cross-section of a typical body-mounted solar

cell. (Note that the layers of material in front of and behind the solar cell act as radiation shielding.)



**Figure 3.3:** Typical solar cell cross-section  
[Rauschenbach:141].

The solar cell array is designed to generate certain voltage and current levels. The satellite's bus voltage is determined by the number of series-connected cells, or "strings" (see Figure 3.4). The bus current is determined by the number of parallel-connected strings [Wertz and Larson:399]. Parallel strings prevent total power loss if a single string fails. Isolation diodes between a string's cells prevent energy from lit cells from damaging shadowed cells. These design techniques lower the overall efficiency of the array, but are necessary for it to operate properly [Wertz and Larson:400].

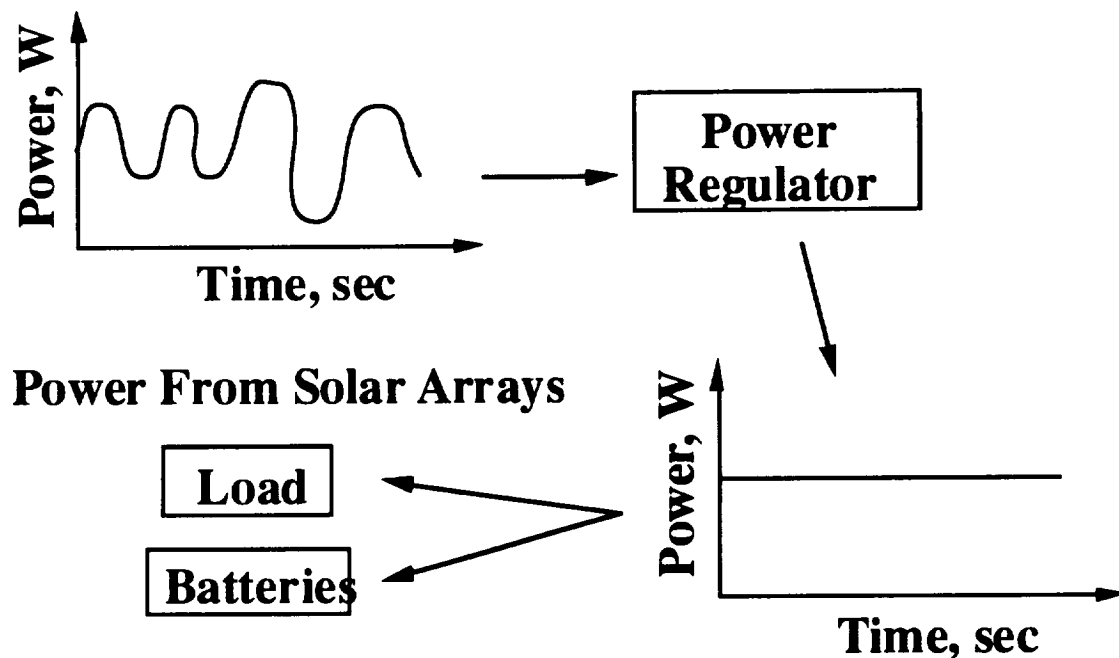


**Figure 3.4:** Series "string" and parallel-connected strings.

The approximate solar array area was found by using an algorithm from *Space Mission Analysis and Design* [Wertz and Larson:356-58]. The various parameters and assumptions used in the spreadsheet calculations may be found in Appendix B, along with the generated data. The sizing yielded an area of  $0.687 \text{ m}^2$  for an omni-directional (spherical) array of silicon solar cells. This area corresponds to a sphere of radius equal to 0.24 m. BATSAT is larger than this ideal size, since it requires extra volume for the instrument package (see Section 2.4). Stabilized, Sun - pointing arrays could be built with less surface area, but such complexity is not necessary for BATSAT. The body-mounted silicon array will provide the 8.6W maximum required power for up to ten years.

### 3.4.2 Power Distribution

The power output of the solar array will vary as BATSAT rotates in the sunlight. A steady power level can be provided by either direct energy transfer or peak-power tracking. Electrical power must then be controlled and distributed to the various loads. Direct energy transfer (DET) uses shunt resistors to dissipate power not being used by the satellite's systems. The DET method is simpler than most methods, but produces waste heat. The peak-power tracker (PPT) "tracks" the solar array's peak-power point to match the satellite's power demands [Wertz and Larson:407], as shown in Figure 3.5. The more efficient PPT is the design choice for BATSAT power regulation.



**Figure 3.5:** Diagram of BATSAT power system.



In addition to a power converter, BATSAT requires a command receiver, relays, wiring, and fuses. The receiver and relays allow ground operators to control the various transmitters. Fuses protect the electronic subsystems in the event of a short circuit.

The loads (payload and battery recharging) require specific voltages from the power source. Since voltage regulators produce electromagnetic interference when used with peak-power trackers, BATSAT will have an unregulated power subsystem. Because the power is unregulated, the load bus voltage must be the same as the voltage of the batteries [Wertz and Larson:407]. Some loads may require further DC-DC conversion to overcome this voltage limitation.

### **3.4.3 Energy Storage**

BATSAT will be equipped with rechargeable batteries in order to operate continuously throughout its mission. The voltage of a battery is determined by the number of series-connected cells in the battery; bus current is determined by the number of batteries in parallel. BATSAT will use nickel-cadmium (NiCd) batteries. NiCd batteries have low energy density, but they are used extensively and are currently the only non-experimental batteries qualified for low Earth orbit [Wertz and Larson:403].

The life cycle of a battery system is the number of times the satellite may switch between charging and discharging of the batteries, and is the primary constraint when sizing the batteries. The longer the cycle life, the less the batteries may be discharged in any one cycle. For a battery

lifetime of five years in low Earth orbit, experience shows that the maximum depth of battery discharge is about 20%, as shown in Figure 3.6.

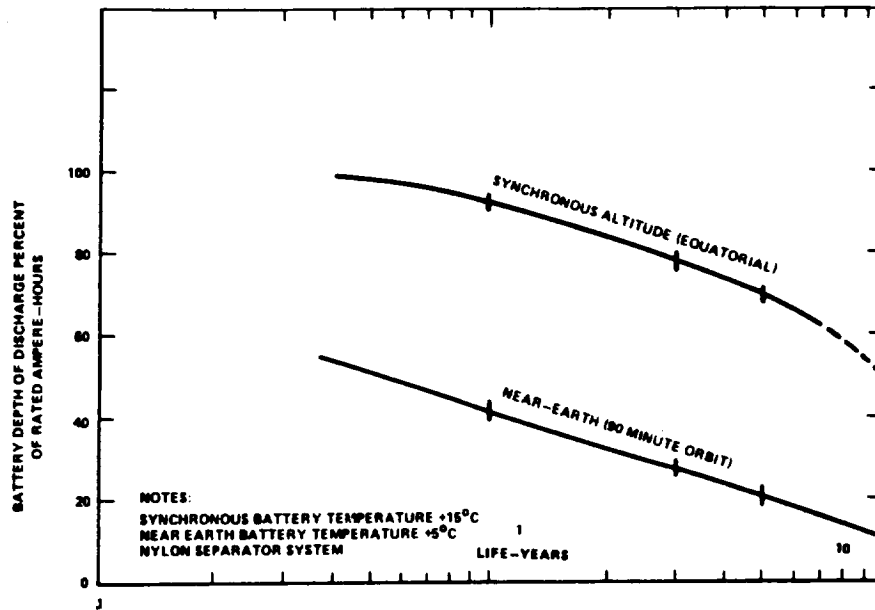


Figure 3.6: Maximum design use of spacecraft NiCd batteries [Source: Chetty:158].

The batteries must have a capacity of 2.06 Amp-hours (see Appendix B for the battery sizing approximation). General Electric manufactures a NiCd cell with a capacity of 3A-h. Connecting twelve of these 1.25V cells in series would provide BATSAT's 15V bus voltage. Normally satellites have a 27.5 V bus voltage, but most of the communication equipment designed by SURFSAT utilizes 15V. One 3A-h cell has a mass of 0.155 kg and a volume of about 70 cm<sup>3</sup>, so the twelve-cell battery is about 1.86 kg and 840 cm<sup>3</sup>. Additional batteries will provide extra capacity and redundancy. More batteries of lower capacity could provide the same initial capacity and partial redundancy. The lower-capacity batteries, however, would have a larger total mass and volume than the higher-capacity batteries [Chetty: 159]. BATSAT will have two 3A-h batteries operating at any given time. A second set of two batteries will be activated

once the first set degrades below an acceptable level. This second set of batteries will allow nighttime operation over the entire ten-year lifetime of BATSAT.

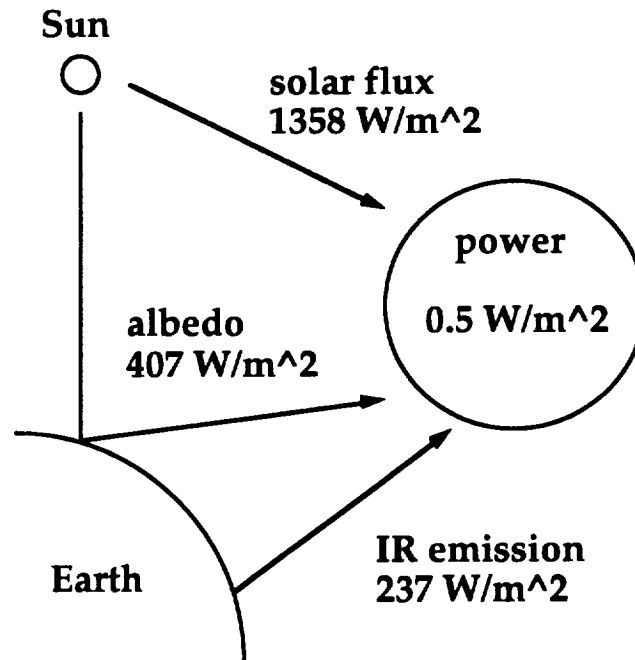
The batteries will be recharged by the solar cells during the lit cycle. Since BATSAT's batteries are not designed to operate more than five years, a simple and inexpensive parallel charging system will be used. Parallel charging does not permit control of the charging current in individual batteries, and can increase battery degradation [Wertz and Larson:409]. Considering BATSAT's size, mass, and lifetime constraints, however, the parallel charger is the best choice.

Rechargeable nickel-cadmium batteries, charging in parallel, are the simplest and most reliable method of storing energy for BATSAT. NiCd batteries work best between temperatures of 5°C and 20°C [Wertz and Larson:318]; the BATSAT thermal environment should be maintained in this range. Also, the batteries will degrade over time, and will not perform well after five years. Therefore the satellite is designed to switch to a second set of batteries after the first set degrades.

### **3.5 Thermal Control**

Figure 3.7 shows BATSAT's thermal environment. Table 3.3 shows the EXCEL spreadsheet used to calculate the thermal flux experienced by BATSAT and the maximum and minimum temperatures experienced. Table 3.4 contains the maximum and minimum allowable temperatures. The table also shows whether BATSAT violates these temperatures. As shown in the tables, both the communications equipment and the batteries

violate the minimum allowable temperatures , while only the batteries violate the maximum temperature constraint.



**Figure 3.7:** BATSAT's thermal environment

BATSAT must employ both active and passive thermal control in order to meet both of the temperature constraints. The exterior of BATSAT will be cold biased by painting the surface not covered by solar cells with white paint. This will ensure that none of the maximum allowable temperatures are reached. Some of the components will now require heating in order to remain above the minimum temperatures. To accomplish this, the batteries and communication equipment will be insulated with a thermal blanket, and strip heaters will be attached to the individual components. These heaters will be connected to a thermostat which will turn them on and off as required. Tables 3.5 and 3.6 show the cold biased thermal environment of BATSAT.

**Table 3.3: BATSAT's Thermal Model Spread Sheet**

| quantity                             | symbol         | value   | units                               | comments  |
|--------------------------------------|----------------|---------|-------------------------------------|---|
| solar constant                       | G <sub>s</sub> | 1363    | W/m <sup>2</sup>                    | worst case hot (wch)  |
|                                      |                | 1353    | W/m <sup>2</sup>                    | worst case cold (wcc)   |
| Earth IR emission                    | q <sub>l</sub> | 258     | W/m <sup>2</sup>                    | wch   |
|                                      |                | 216     | W/m <sup>2</sup>                    | wcc   |
| albedo                               | a              | 0.35    | none                                | 35% multiplier of solar constant wch  |
|                                      |                | 0.25    | none                                | 25% multiplier of solar constant wch  |
| electric pow. dissapt'n              | Q <sub>w</sub> | 0.52    | Watts                               | assumed value of 5% of peak power (10.4 W) wch  |
|                                      |                | 0       | Watts                               | everything off wcc  |
| Stefan-Boltzman const                | s              | 5.7E-08 | W/(m <sup>2</sup> •K <sup>4</sup> ) |   |
| solar absorptivity                   | a              | 0.805   |                                     | 100% solar array surface  |
| IR emissivity                        | e              | 0.825   |                                     | 100% solar array surface  |
| angular radius of Earth              | r              | 1.00844 | radians                             | derived from<br>arcsin[RE/(h+RE)]   |
| Earth radius                         | RE             | 6378000 | meters                              |   |
| altitude                             | h              | 1161000 | meters                              |   |
| Sun -Earth factor                    | K <sub>a</sub> | 0.98296 | none                                | accounts for collimated solar energy off of spherical Earth<br>K <sub>a</sub> = .664+.521(rho)-<br>.203(rho) <sup>2</sup> |
| solar array efficiency               | h              | 0.1     | none                                | reasonable value  |
| diameter of sphere S/C               | D              | 0.3     | meters                              |   |
| <b>Worst Case Hot Temp (Tmax) =</b>  |                |         | 33.55638455 degrees C               |   |
| <b>Worst Case Cold Temp (Tmin) =</b> |                |         | -90.9764684 degrees C               |   |

(source: Wertz & Larson pg. 423-425)

**Table 3.4: Allowable temperature ranges**

| Component    | Temp Range (deg C) | hot limit exceeded | cold limit exceeded |
|--------------|--------------------|--------------------|---------------------|
| electronics  | 0 to 40            | no                 | yes                 |
| batteries    | 5 to 20            | yes                | yes                 |
| solar arrays | (-100) to 100      | no                 | no                  |
| structures   | (-45) to 65        | no                 | yes                 |

(source: Wertz & Larson pg. 410)

**Table 3.5: BATSAT cold biased thermal environment**

| Quantity                      | symbol     | value  | units                               | comments  |
|-------------------------------|------------|--------|-------------------------------------|---|
| solar constant                | Gsh        | 1363   | W/m <sup>2</sup>                    | worst case hot (wch)  |
|                               | Gsc        | 1353   | W/m <sup>2</sup>                    | worst case cold (wcc)   |
| Earth IR emission             | qlh        | 258    | W/m <sup>2</sup>                    | wch   |
|                               | qlc        | 216    | W/m <sup>2</sup>                    | wcc   |
| albedo                        | ah         | 0.35   | none                                | 35% multiplier of solar constant wch  |
|                               | ac         | 0.25   | none                                | 25% multiplier of solar constant wch  |
| electric pow. dissapt'n       | Qwh        | 1.1334 | Watts                               | assumed value of 15% of peak power wch  |
|                               | Qwc        | 0      | Watts                               | everything off wcc  |
| Stefan-Boltzman const         | $\sigma$   | 6E-08  | W/(m <sup>2</sup> •K <sup>4</sup> ) |   |
| solar absorptivity            | alpha      | 0.68   |                                     | for 80% solar and 20% wt. paint   |
| IR emissivity                 | $\epsilon$ | 0.863  |                                     | for 80% solar and 20% wt. paint   |
| angular radius of Earth       | $\rho$     | 1.008  | radians                             | derived from arcsin[RE/(h+RE)]  |
| altitude                      | h          | 1163.1 | meters                              |   |
| Sun -Earth factor             | Ka         | 0.9829 | none                                | accounts for collimated solar energy off of spherical Earth<br>Ka=.664+.521(rho)-.203(rho) <sup>2</sup> |
| diameter of sperical S/C      | D          | 0.47   | meters                              |   |
| Worst Case Hot Temp (Tmax) =  |            |        |                                     | 19.6 °C   |
| Worst Case Cold Temp (Tmin) = |            |        |                                     | -91.3 °C  |

**Table 3.6: Allowable temperature ranges**

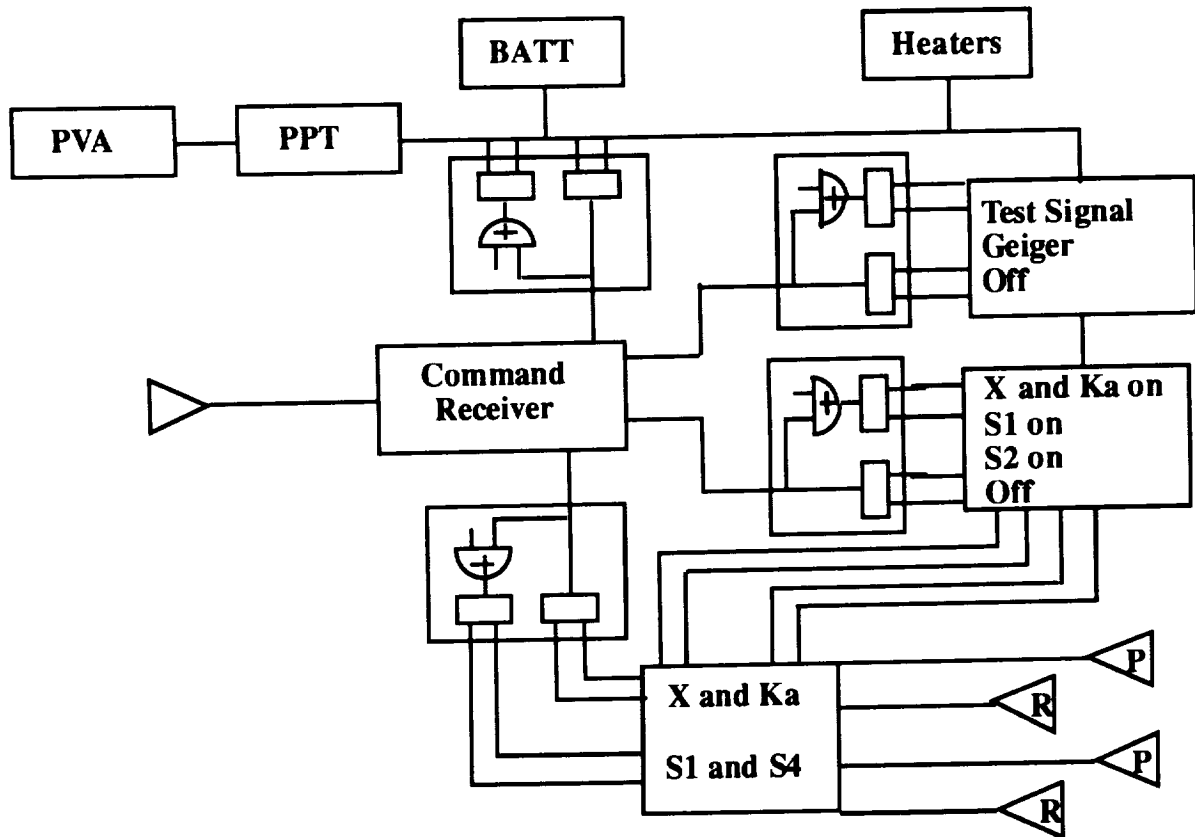
| Component    | Temp Range (deg C) | hot limit exceeded | cold limit exceeded |
|--------------|--------------------|--------------------|---------------------|
| electronics  | 0,40               | n                  | y                   |
| baterries    | 5,20               | n                  | y                   |
| solar arrays | (-100),100         | n                  | n                   |
| structures   | (-45),65           | n                  | y                   |

### **3.6 Command System**

BATSAT uses a 4 pulse-cyclic command system for each of the four major sections: power, transmitters, redundant antennae, and sensor. The ground station sends individual pulses to the satellite, and the command system cycles through the modes of a particular system until the desired mode is reached. One of the problems of this type of command system is that the ground station is not always able to determine the command state of the satellite. Therefore, BATSAT's command system has a reset option, which will return the system to an origin state, and then commanding can begin. If a pulse is sent to nodes on the individual logic circuits, the cyclic logic circuits will all reset to an initial state.

The power system will also have an automatic toggle to the solar arrays if the batteries fail during operation. This toggle ability allows the satellite to provide power for the command receiver when the satellite comes out of an eclipse period. Figure 3.8 is a simplified block diagram of the command system.

The communication-system commands allow BATSAT to transmit over the operational modes discussed earlier. The antenna commands provide the capability to switch from the primary to the redundant set of antennas. This switch can be performed for two sets of antennas. The first set is the X and Ka-Band antennas. Since BATSAT will always be transmitting over these two bands simultaneously, BATSAT will switch both sets from primary to redundant at the same time. BATSAT also has the ability to switch from primary to redundant antennas for the S band system.



**Figure 3.8:** Simplified BATSAT command system and system block diagram.

### 3.7 Recommendations

Future groups that work on this project will need to characterize the interference patterns generated by the multiple antennae. This will entail building a mock satellite, placing the antennae as they will be on BATSAT, and then transmitting and characterizing the signal received. This process will help generate the filter for operations. Also, the SURFSAT communication equipment needs to be better integrated into the BATSAT design. Finally, future groups will need to generate more detailed

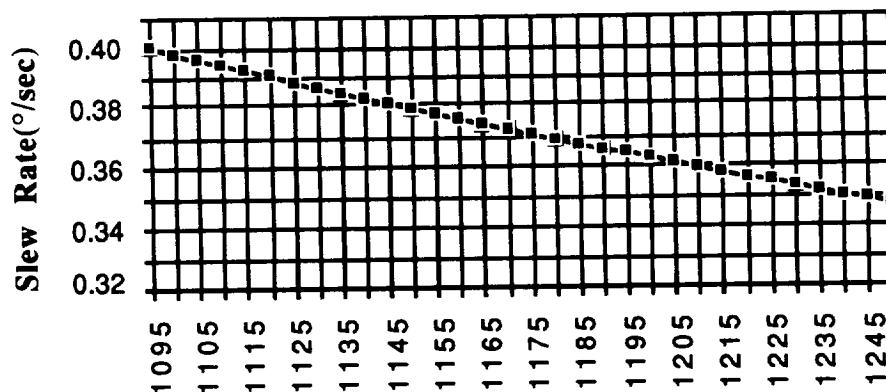


schematics of the power system. Mockingbird's work in this area has basically been at a block diagram level. If the satellite is to be produced at UT, a detailed wiring schematic will need to be made. The University plans to use student design courses in the Electrical Engineering Department to design, build, and test the extra electronics hardware needed by BATSAT.

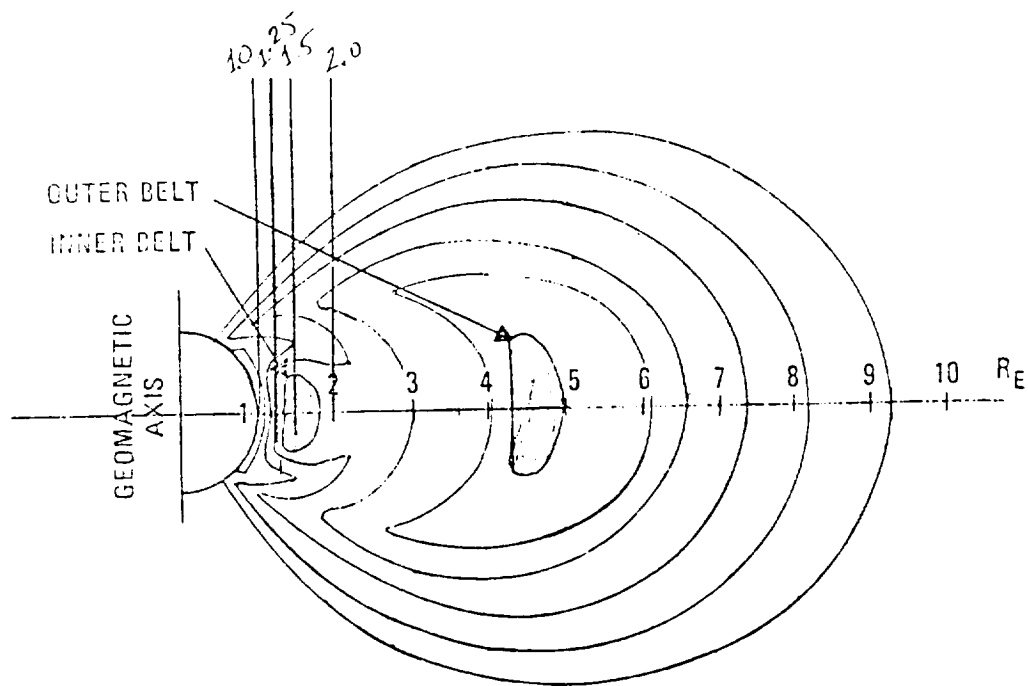
## 4.0 ORBIT DETERMINATION

### 4.1 Requirements and Constraints

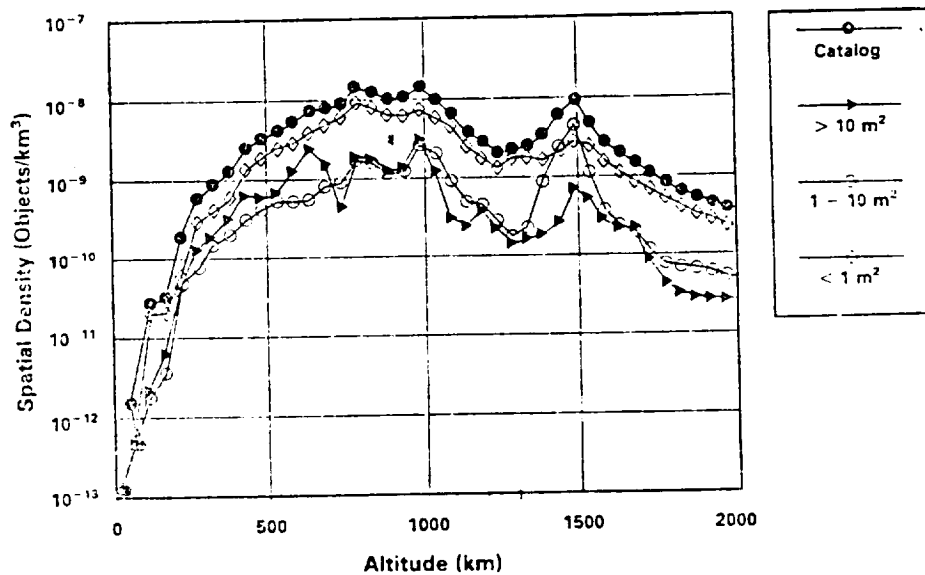
In order to determine the most appropriate orbit for BATSAT, the requirements and constraints imposed by the mission goals were considered. The maximum slew rate of the 34-meter DSN dishes that will be used to observe the satellite is  $0.4^\circ/\text{sec}$ . Figure 4.1 is a plot of the necessary dish slew rate as a function of altitude; it shows that the minimum possible altitude that fulfills this constraint is 1095 km. On the upper end of the altitude scale, the Van Allen Radiation Belts become a problem. The intensity of the Van Allen belts increases considerably beyond an altitude of 1276 km (see Figure 4.2). These two constraints limit the orbit altitude to a range of less than 200 km. Fortunately, there also happens to be a lower concentration of space debris in this altitude range (Figure 4.3). The final constraint on the BATSAT orbit is the locations of the DSN dishes. A minimum orbit inclination of  $40^\circ$  is required to pass over each of the three DSN dishes at Goldstone, Canberra, and Madrid.



**Figure 4.1:** Groundstation Slew Rate vs. Satellite Altitude



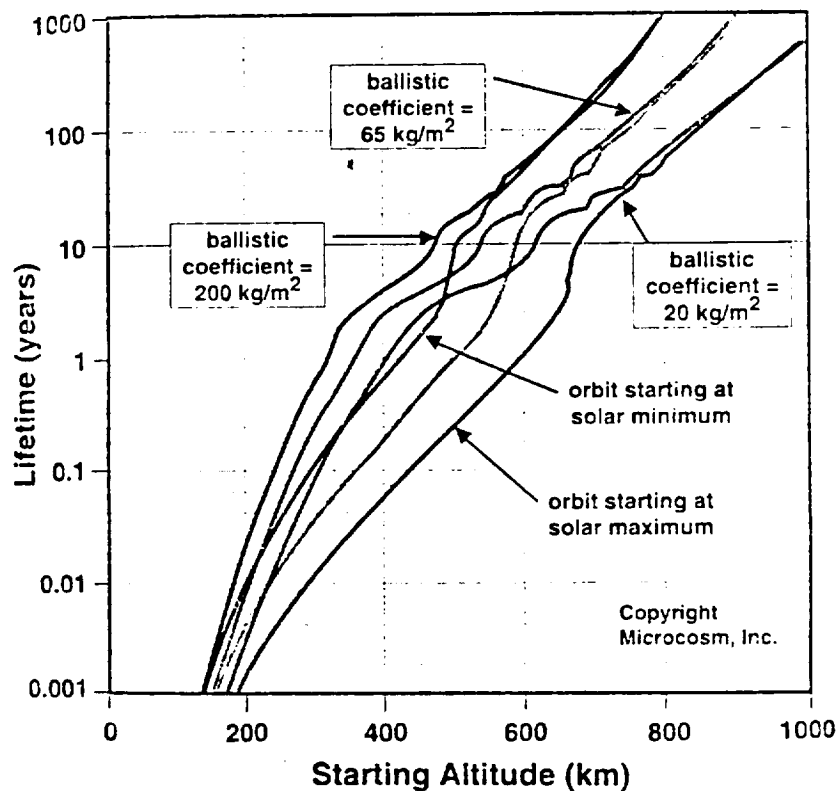
**Figure 4.2:** Van Allen Radiation Belt intensity vs. altitude  
 [Source: NASA, 1989]



**Figure 4.3:** Orbital debris density vs. altitude.  
 [Source: Wertz and Larson]

## 4.2 Orbital Parameters

The orbital parameters chosen for this mission are based upon a seven-day repeat groundtrack cycle. The altitude of the orbit is 1163 km, with a corresponding semi-major axis of 7541 km. The orbit eccentricity is zero and the inclination is  $70^\circ$ . This orbit has a 1.81 hour orbital period with a corresponding slew rate of  $0.375^\circ/\text{sec}$ . The decay rate of this orbit, shown in Figure 4.4, is approximately 0.25 km/yr.



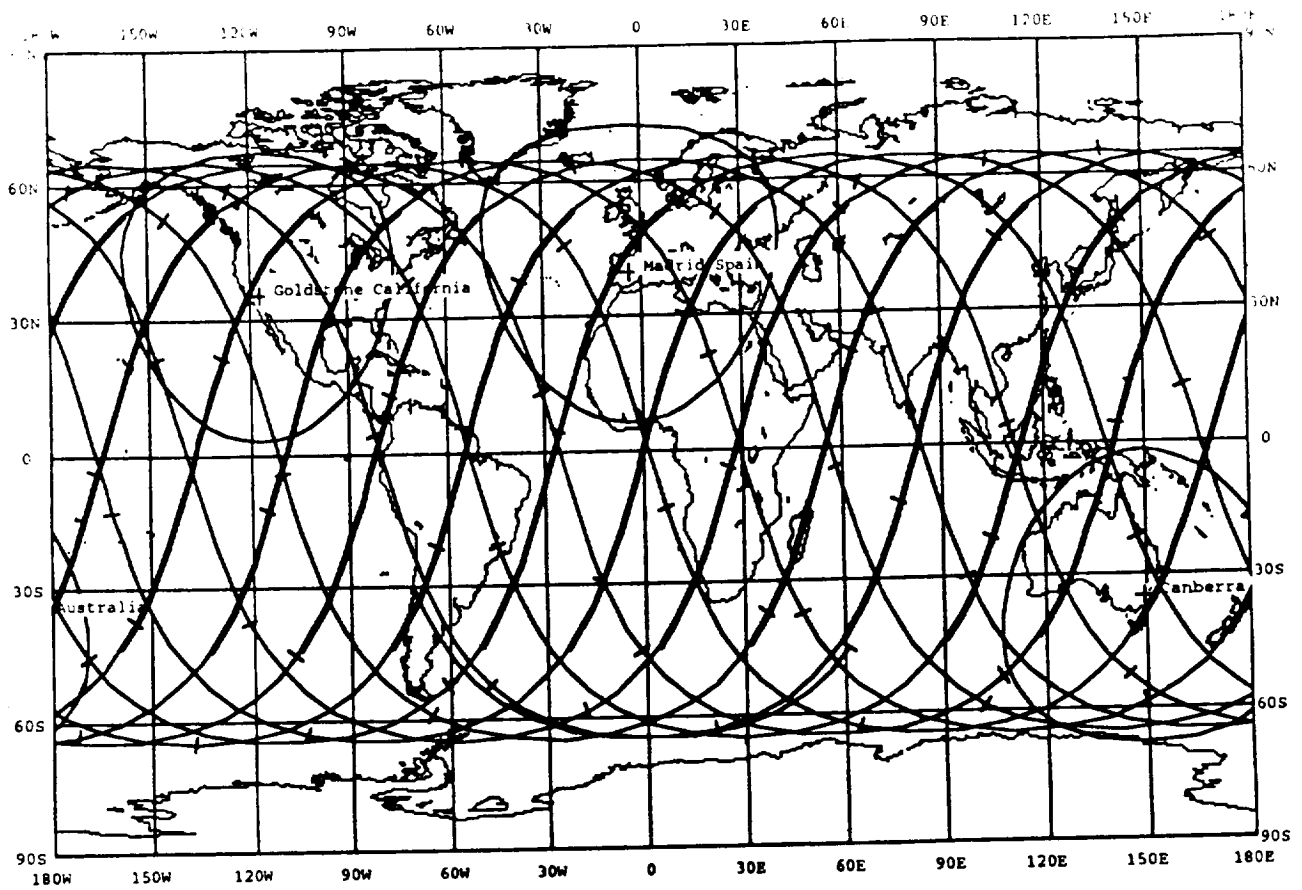
**Figure 4.4:** Orbital decay rate.  
[Source: Wertz and Larson]

### **4.3 Groundtrack Characteristics**

A seven-day repeat groundtrack was chosen in order to make it easier to predict the viewing time for the DSN dishes, and to simplify tracking schedules. BATSAT will make 92 revolutions every 7 days. Figure 4.5 is a 1-day plot of the groundtracks for the orbit selected. The three DSN dishes will each receive an average of 85 minutes of data per day for a total of about 28 hours of data per week.

### **4.4 Future Work**

Several questions must be addressed prior to the BATSAT launch. In order to avoid the risk of colliding with other satellites, the availability of the 1163 altitude for BATSAT must be checked. Also, more information about the groundstation viewing capabilities is needed to confirm the current time estimates. In addition, the eclipse periods for the orbit need to be compared to groundstation viewtimes so that the BATSAT battery requirements can be better determined.



**Figure 4.5:** Groundtrack plot of BATSAT for one day.

## 5.0 LAUNCH SELECTION

Many factors were involved in determining the best launch choice for the BATSAT mission. Clearly, the launch vehicle must be capable of lifting the required mass to the requisite altitude with the appropriate inclination. The vehicle must also be able to accommodate the size and shape of its payload. Other considerations include:

- Reliability, availability, and cost of launch vehicle
- Environmental conditions during launch
- Attitude control and spin stabilization
- Orbital injection accuracy
- Launch integration flexibility.

Because of the superiority of the Pegasus launch vehicle in all of the decision factors, Mockingbird Designs has chosen the Pegasus as the primary launch choice for the BATSAT mission (see Figure 5.1).

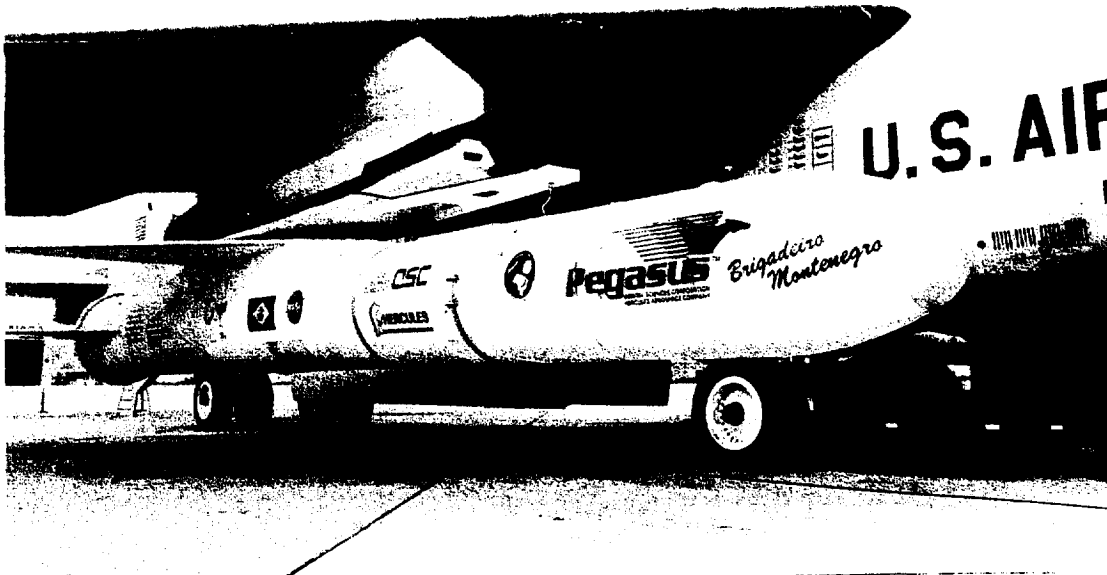
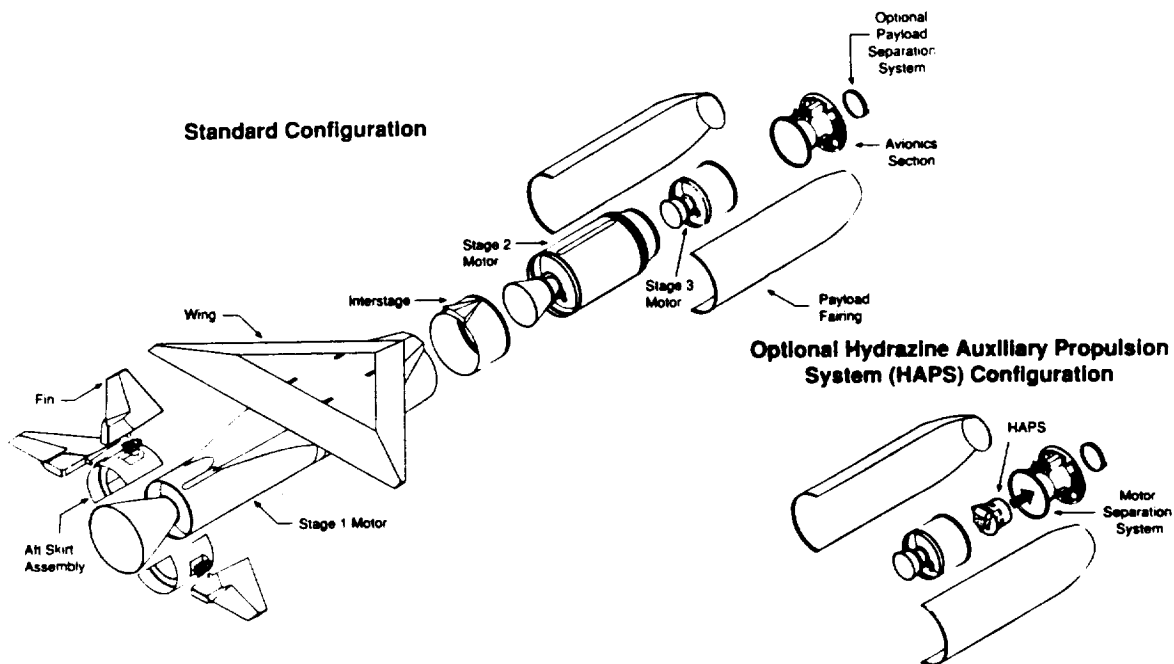


Figure 5.1: Pegasus Space Booster under the wing of B-52

## 5.1 Primary Launch Scenario

Pegasus is a three-stage, solid propellant space booster that uses inertial guidance. The booster is made entirely of composites, and unlike other launch vehicles, it has a wing as shown in Figure 5.2. The rocket is mounted to a modified Lockheed L-1011 carrier operating out of the west coast integration site at Edwards Air Force Base, California. Prior to ignition, the aircraft approaches level flight at about 41,000 ft and Mach 0.8, at any location in the Western Test Range. Appendix D contains an example launch profile timeline for a Pegasus mission.



**Figure 5.2:** Exploded-view of Pegasus booster.

After release from the aircraft and ignition of its first stage motor, Pegasus' autonomous guidance and flight control system controls all of the maneuvers necessary to insert payloads into a wide range of orbital



configurations. Advanced propulsion, structural and avionics technologies, and an optimized, lift-assisted trajectory give Pegasus roughly twice the lifting capability of other small launch vehicles, with superior performance and cost efficiency [Isakowitz: p218]. In addition to the technical advantages of the Pegasus launch vehicle, its parent company, Orbital Sciences Corporation (OSC), provides full engineering and management support, including mission planning, structural integration, and a full range of standard and optional mission services [Pegasus User's Guide:2-1].

The cost of Pegasus is estimated between \$7-\$12 million (1990\$), making it one of the least expensive small launch vehicles [Isakowitz:p219]. The reason for the wide variation in cost is because of the highly flexible nature of the Pegasus launch vehicle. Since BATSAT will use the optional Hydrazine Auxiliary Propulsion Stage (at an extra cost of about \$1.5 million), OSC estimates a \$9 million launch cost for the BATSAT mission [OSC fax].

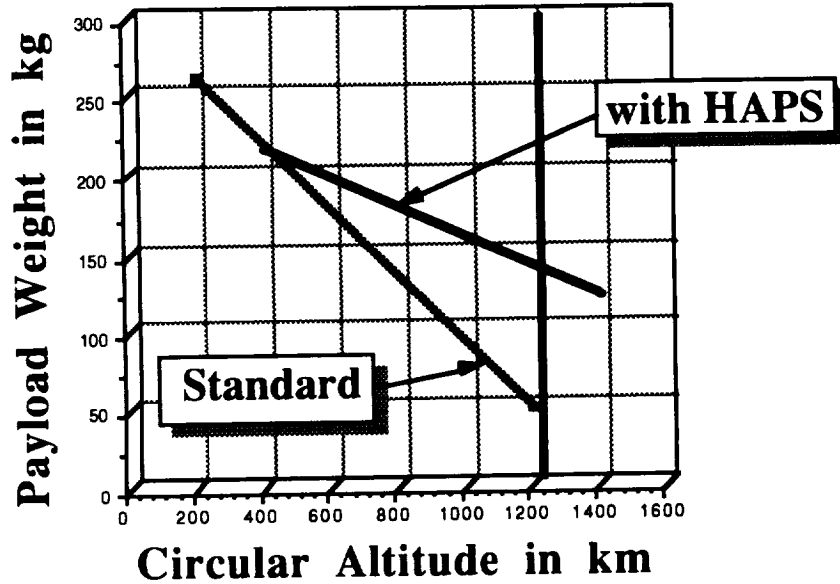
### **5.1.1 Launch Performance**

The most important characteristic of a launch vehicle is its lifting capacity. Figure 5.2 is a plot of Pegasus lift capability to polar orbit [Pegasus User's Guide:3-4]. For an orbit of 1200 km altitude and 70° inclination, the basic three-stage Pegasus configuration can lift about 70 kg payload mass, sufficient for BATSAT mission requirements. With the standard configuration, Pegasus injection accuracy (for 3 normal standard deviations) into low Earth orbit is roughly  $\pm 50$  km altitude and  $\pm 0.5^\circ$  inclination [Pegasus User's Guide:3-6]. In addition, for launches in 1993 and later, Pegasus will be using production lot 2 motors that will improve

payload performance by 8% to 20% above that for lot 1 motors (the ones that the data describe) [Pegasus User's Guide:3-3].

For the BATSAT mission, Pegasus will be configured with the optional Hydrazine Auxiliary Propulsion System (HAPS). HAPS improves injection accuracy by a factor of ten and increases payload capability to higher orbits (see Figures 5.3 and 5.4). HAPS consists of a hydrazine propulsion subsystem and a Stage 3 separation subsystem, and is mounted inside the Pegasus avionics structure. After burn-out and separation of the Stage 3 motor, the HAPS thrusters are used to provide additional velocity and to perform precise orbit injection with an accuracy better than  $\pm 0.5^\circ$  for spin axis pointing [Pegasus User's Guide:2-8].

Either an inertial-fixed or spin-stabilized attitude can be chosen, with a maximum spin rate of approximately 160 rpm. The actual maximum spin rate and rotation accuracy depends on the moment of inertia of the payload and the amount of the HAPS propulsion budget needed for other attitude control maneuvers [Pegasus User's Guide:3-6]. Mockingbird must determine the optimal satellite spin rate based upon thermal and communication constraints.



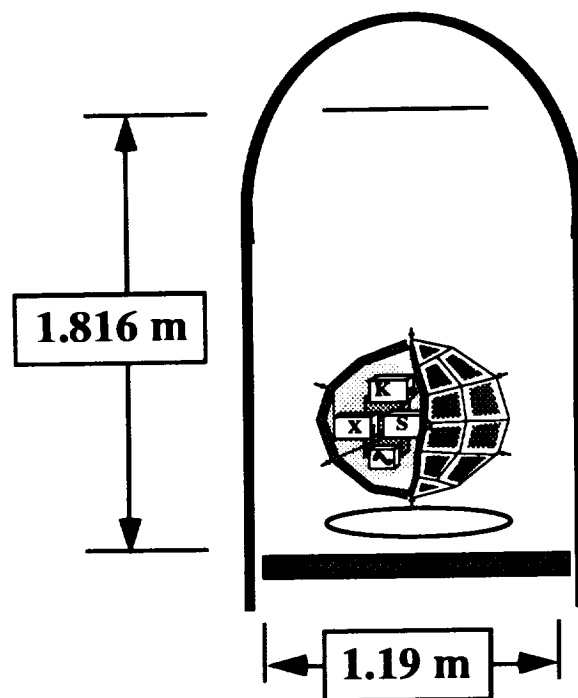
**Figure 5.3:** Pegasus lifting capability to circular polar orbits.

| <b>3<math>\sigma</math> variation</b> | <b><u>Standard</u></b>           | <b><u>with HAPS</u></b>           |
|---------------------------------------|----------------------------------|-----------------------------------|
| <b><u>Altitude</u></b>                | <b><math>\pm 50</math> km</b>    | <b><math>\pm 5.6</math> km</b>    |
| <b><u>Inclination</u></b>             | <b><math>\pm .5^\circ</math></b> | <b><math>\pm .05^\circ</math></b> |

**Figure 5.4:** Orbital injection accuracy for Pegasus.

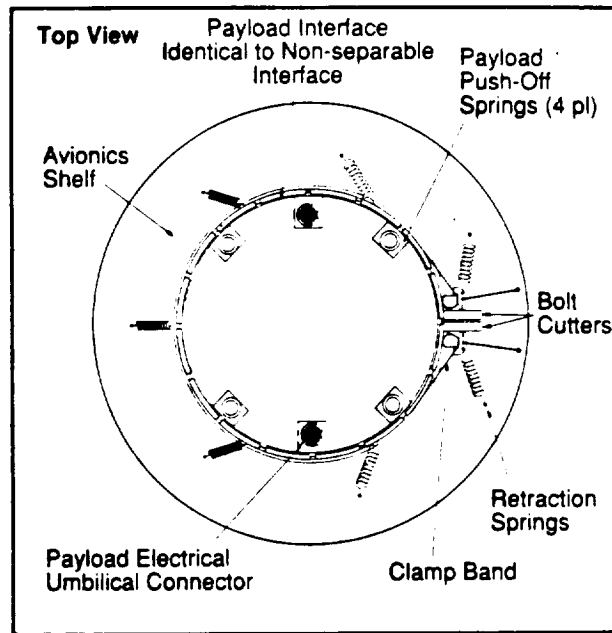
### 5.1.2 Payload Integration

The Pegasus payload fairing provides ample room for BATSAT. In fact, there is enough excess space to allow a second (and perhaps a third) payload to share a launch using the HAPS. Figure 5.5 shows the rough dimensions of the Pegasus payload fairing [Pegasus User's Guide:5-4].



**Figure 5.5:** Payload fairing dimensions for Pegasus

OSC provides all hardware and integration services necessary to attach BATSAT to Pegasus [Pegasus User's Guide:5-2]. OSC offers a standard mechanical separation interface and will provide an adapter and all necessary attachment hardware and will perform all integration functions [Pegasus User's Guide:5-6]. The interface is a Marmon clamp design with a 24.5 cm diameter bolt circle (see Figure 5.6)



**Figure 5.6:** Separable payload interface.

Since BATSAT uses the standard Pegasus payload separation system, OSC will control the entire spacecraft separation process. At the time of separation, redundant bolt cutters sever the connections to the avionics subsystem, and the payload is ejected by four push-off springs supplying an initial force of 334 N (75 lbf) each, with sufficient energy to give BATSAT a separation velocity of more than 3 m/s [Pegasus User's Guide:5-7]. HAPS then performs a collision and contamination avoidance maneuver to avoid damaging the separated payload [Pegasus User's Guide:3-6].

### 5.1.3 Launch Constraints

The *Pegasus Payload User's Guide* provides extensive detail on the payload environment during L-1011 captive carry and launch, as well as structural design constraints on the payload. The *User's Guide* details the payload structural safety factors required by OSC; Appendix D contains a

table summarizing these requirements [Pegasus User's Guide:4-1].

Constraints caused by launch availability are minimal due to the open launch manifest and flexibility of the Pegasus.

The payload acceleration environment during ground operations and captive carry is mild and does not exceed 1.5 g's. The static axial accelerations for the end of Stage 2 and Stage 3 burns vary with payload mass, and have a maximum of 11 g's acceleration for a mass of 50 kg [Pegasus User's Guide:4-3]; since BATSAT will have a mass in this range, this was taken as the design constraint. In addition, launch accelerations in the lateral directions can reach 3 g's [Pegasus User's Guide: 4-3].

Appendix D, contains plots describing the acceleration, acoustic, shock, and vibration environments [Pegasus User's Guide].

The payload thermal environment is maintained between 64°F and 84°F, with less than 50% humidity, through ground operations and captive flight. The L-1011 provides filtered air-conditioning during captive flight through an A/C port in the Pegasus payload fairing [Pegasus User's Guide:4-6]. OSC has a comprehensive contamination control program to minimize the payload's exposure to contamination through orbital insertion and separation; the primary means of protection are through passive barriers in the payload fairing [Pegasus User's Guide:4-7].

Payload radio-frequency transmissions are not permitted prior to separation of the payload for standard services [Pegasus User's Guide:5-11]. Fortunately, BATSAT will not require any communication prior to separation.

There are few structural constraints that BATSAT must meet to use the Pegasus launch vehicle. To satisfy bending and buckling load constraints on the avionics and HAPS structures, BATSAT's center of mass

is required to be within 2.5 cm of the vehicle centerline [Pegasus User's Guide:5-10]. In addition, strict mass property measurement tolerances must be adhered to; these are tabulated in Appendix D. Most important for the BATSAT preliminary design is the constraint on payload stiffness. To avoid dynamic coupling of the payload modes with the 12 Hz natural frequency of the Pegasus vehicle, BATSAT must be designed with a structural stiffness that will ensure that the fundamental frequency in the transverse direction is greater than 20 Hz [Pegasus User's Guide:5-11].

Section 2.0 of this report details how the BATSAT structural design deals with the Pegasus payload constraints. With the current design, BATSAT satisfies the mass center-line, acceleration, and frequency constraints by large margins of safety.

## **5.2 Secondary Launch Options**

### **5.2.1 Piggyback**

Early in the BATSAT design, the option of attaching to another satellite or its spent rocket booster was considered as a possible method of reducing launch costs. The SURFSAT preliminary design choice involves a piggyback on the booster stage used to deploy the LAGEOS satellite. There are several major problems with this option that resulted in its rejection by Mockingbird.

If BATSAT were attached to another object without attitude control, BATSAT's antennae would often be shielded from the Earth, resulting in signal blinking that would interfere with data acquisition by the DSN dishes. Mockingbird prefers consistent, continuous data transmission to

satisfy the mission goals. Also, the large booster stage could shadow the solar cells, causing irregular and unpredictable power.

Another serious constraint imposed by a piggyback option is that BATSAT would be dependent upon the orbit and launch choices made by the primary payload. This would result in unacceptable interference with Mockingbird's design efforts and project autonomy. In addition, integration would be complicated and could not be handled satisfactorily during preliminary design.

### **5.2.2 Scout Launch Option**

The Solid Controlled Orbital Utility Test (SCOUT) launch vehicle is a four-stage space booster capable of lifting over 100 kg to the BATSAT primary orbit choice (1163 km altitude, 70° inclination) [Isakowitz:238]. SCOUT has an open loop inertial guidance system located on the third stage. The fourth stage is spin stabilized and the optional fifth stage has an attitude control system [Isakowitz:234]. Several different payload fairing sizes are available, the largest of which is slightly smaller than the Pegasus fairing [Isakowitz:236]. SCOUT has estimated launch costs of \$10-\$12 million (1990\$); this price is more than the \$9 million estimated launch costs for Pegasus. The SCOUT vehicle fulfills the requirements of a launch vehicle for BATSAT, but since it offers no advantages over the Pegasus, and is in some ways inferior to it, Mockingbird has rejected it as a launch option.



### **5.2.3 Military Options**

One alluring option available to Mockingbird is the use of military surplus to loft BATSAT into orbit. With an increasing surplus of conventional and nuclear rockets, the U.S. Government has hinted that these rockets could be used for peaceful space applications. Since BATSAT will be a university sponsored project, the government may be more willing to allow this option. A very promising rocket is the SPARTAN, which has been successfully used to launch payloads to orbit. However, built as an interceptor, the SPARTAN's launch loads approach an imposing 22 g's. Mockingbird plans to research this possible option, along with other military surplus possibilities.

### **5.2.4 Shared Launch**

Another promising possibility for reducing the launch costs for BATSAT is to share a launch vehicle with other small payloads that require a similar orbital altitude. Possible launch vehicles being investigated for this option include Ariane, Pegasus, and OSC's new Taurus booster. In order to preserve the design choices that have already been made, the focus has been on the Pegasus shared launch option.

Pegasus payload interfaces can accommodate multiple payloads on a single flight. To date, as many as seven independently deployed spacecraft have been manifested on a single mission [User's Guide:5-10]. OSC maintains a manifest of future missions whose volume and performance requirements offer a margin for additional payloads. An example of a

possible shared launch option is launching BATSAT in conjunction with one or two high inclination ORBCOMM satellites (see Figure 5.7). ORBCOMM is a global communications network that consists of a constellation of 26 small satellites to be launched over the next two years [Thompson:15].



**Figure 5.7:** ORBCOMM satellites.

Since BATSAT's current design volume is less than half the size of the Pegasus payload fairing, it is possible that a secondary payload could be found to share the launch vehicle. Both Stage 3 Reaction Control and the HAPS propulsion subsystem have the capability to incrementally orient the final stage for the deployment of multiple spacecraft with independent attitude requirements [User's Guide:3-6]. For additional cost, OSC will provide structures for mounting, pointing, and/or independently deploying multiple payloads [User's Guide:5-10].

## **6.0 MANAGEMENT AND COST**

### **6.1 Management Goals**

Due to limited time and a complex project, efficient management of the BATSAT program was essential. The Mockingbird management team implemented a dynamic program plan to fulfill the BATSAT Mission Statement. The management goal was to promote efficient work in the group, evenly distribute work to the entire team, prevent communication bottlenecks, and to identify and remedy potential problems before they happened. The primary method of achieving this goal is to promote good communication of information and problems between individual subsystem groups as well as with management. Therefore a strong communication hierarchy was established by Mockingbird management at the beginning of the project.

### **6.2 Program Organization**

The upper management remained constant throughout the program lifetime, which is essential to program efficiency and organization. Figure 6.1 shows the Mockingbird organizational structure at the end of the project. The three major management positions were the Program Manager, Chief Engineer, and the Chief Administrative Officer. Dennis McWilliams, Mockingbird's Program Manager, served as Mockingbird's primary point of contact throughout the project. He kept the contract monitor informed of major organizational changes, work progress, and any major problems. The Program Manager set project goals, defined project milestones, assigned workloads, and adjusted manpower. The

Program Manager also assigned initial action items for individual groups until the groups became more self-sufficient.

The Chief Engineer (CE) for the project was Clint Slatton. Mr. Slatton managed the technical problems of the project by serving as liaison between Mockingbird and technical contacts in industry. The CE took the milestones and project goals from the Program Manager and turned them into precise technical action items. The Chief Engineer also served as the bridge between subsystem leaders and management. Therefore the CE was a major communication link between the engineering level and management level.

The Chief Administrative Officer (CAO), Cassidy Norman, was in charge of organizing all project records, analyzing personnel reports, computing program costs, and maintaining the project notebook. The CAO also kept track of the completion of action items, and established a Gantt Chart showing different non-technical due dates for the project.

The remaining organizational structure was broken down into several subsystem groups that were modified throughout the project to meet project needs. Each subsystem group was headed by a subsystem leader who assigned work to subordinate engineers. Prior to Preliminary Design Review 1, the subsystems were CPS (Communication, Power, and Structure), Orbits, and Launch Systems. After PDR1, the Launch Systems group and Orbits group saw a decrease in man-hours, while the CPS group saw an increase in man-hours. Therefore the CPS group was split into a Communication and Power group and a Structures group. Engineers were transferred from the Launch Systems and Orbit Groups to fill workload requirements with no loss in efficiency or organization. This change is reflected in the organizational chart shown in Figure 6.1.

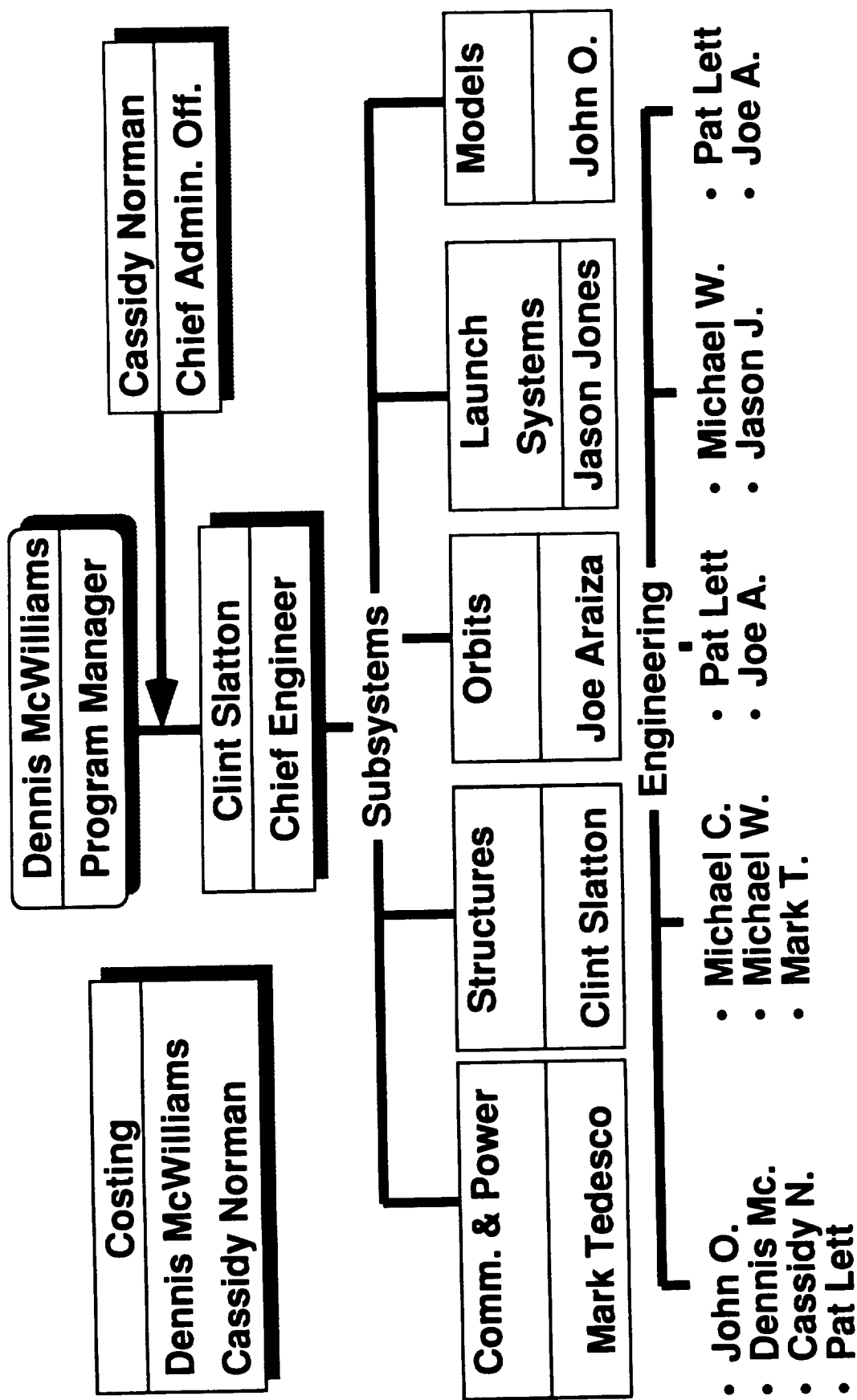


Figure 6.1: Project organization after PDR 1.

### **6.3 Communication Aids**

Several techniques were used to maintain a strong communication link throughout the team. To keep project complexity and salary costs low, only ten people were assigned to this project. Since the team size was small, the team members could be involved in several different groups to intertwine the organizational structure. In order to increase the effective strength of our team as well as improve communication, all members served in two positions in the program. Upper managers (PM, CE, and CAO) served as engineers in the Subsystem Groups, and subsystem leaders served as engineers in other subsystem groups if possible. All other personnel served as engineers in two different subsystem groups. During the course of the project, the engineers could easily be switched from one subsystem group to another without serious loss in efficiency. This could be accomplished because all subsystem design choices were discussed during team meetings, and therefore all team members knew the technical concerns of other systems.

The organizational chart reveals the quick access managers had to the engineers. Broad project goals were set at the upper management level, and these goals were transformed into specific tasks, or action items, by the Program Manager and Chief Engineer. The action items were given numbers specific to the subsystem group they pertained to. The actions were assigned via memos and recorded on a list to provide a written record. Upon completion of an item it was checked complete and left on the list for record. The action item method provided good communication between management and engineers, and kept the group on schedule. It also allowed managers to study the work load in each department and see if

more manpower was needed in a certain area. Engineers also had an easy and short communication link to upper management. Engineers could relay problems to their subsystem leader, who in turn gave the message to management. During critical times in a subsystem's design, each subsystem group contained one upper-level manager working as an engineer. Therefore these manager-engineers could directly see the problems and successes of a group. Finally, all team members attended the Mockingbird Team meeting every Monday, Wednesday, and Friday (and more if needed). During these meetings all members could bring up problems and questions concerning engineering, scheduling, or management.

#### **6.4 Program Control and Schedule**

The BATSAT Project required a well planned schedule and control scheme. Due to the nature of designing a satellite system, many subsystem design tasks depend on the choice for another subsystem. Thus certain subsystem work had to be completed before other work could begin. Also, these requirements had to be completed before certain critical dates such as Preliminary Design Reviews 1 and 2, Final Review, Final Report, etc. These constraints made a PERT chart invaluable for the effective management of the project. The overall PERT chart used for the Mockingbird BATSAT Project is given in Figure 6.2. This PERT chart lists the major project milestones along the critical path, and shows which project tasks had to be completed before others could begin. The dates given in boldface were critical dates and for the most part remained constant. They provided bounds on the other subsystem tasks that had to be completed beforehand. The PERT Chart also provided the basis for a

program Gantt chart given in Figure 6.3. The Gantt chart was posted in the Mockingbird office and was reviewed during the daily meetings. These tools provided a basis for a tight work schedule and let management foresee any problems should a specific milestone date slip. Table 6.1 shows certain project milestones, their estimated start and stop times, and the actual start and stop times. For the most part the project did stay on its tight schedule, which is one reason it was so successful.



**Table 6.1: Project Milestone Schedule**

| <b>BATSAT Design<br/>Project Task</b> | <b>Sched.<br/>Start</b> | <b>Actual<br/>Start</b> | <b>Sched.<br/>Finish</b> | <b>Actual<br/>Finish</b> |
|---------------------------------------|-------------------------|-------------------------|--------------------------|--------------------------|
| Conceptual Design Review              | 1/19                    | 1/19                    | 2/12                     | 2/12                     |
| Proposal                              | 2/12                    | 2/12                    | 3/1                      | 3/1                      |
| Orbit Choice                          | 2/14                    | 2/14                    | 3/2                      | 3/2                      |
| Launch System Choice                  | 2/14                    | 2/14                    | 3/3                      | 3/3                      |
| Preliminary Structure Design          | 2/14                    | 2/14                    | 3/5                      | 3/5                      |
| Main Power Design                     | 2/14                    | 2/14                    | 3/3                      | 3/3                      |
| Transponder Integration               | 3/4                     | 3/4                     | 3/4                      | 3/4                      |
| Antenna Design                        | 3/4                     | 3/4                     | 3/4                      | 3/4                      |
| <b>PDR1 Oral Report</b>               | 3/19                    | <b>3/23</b>             | 3/19                     | <b>3/23</b>              |
| PDR1 Written Report                   | 3/12                    | 3/12                    | 3/29                     | <b>4/2</b>               |
| Payload Integration                   | 3/10                    | 3/10                    | 4/16                     | 4/16                     |
| Structure Integration                 | 3/10                    | 3/10                    | 4/16                     | 4/16                     |
| <b>Model Construction</b>             | 3/24                    | 3/24                    | 4/24                     | <b>5/6</b>               |
| <b>Spacecraft Integration</b>         | 4/19                    | 4/19                    | 4/24                     | <b>4/19</b>              |
| PDR2 Oral Report                      | 4/26                    | 4/26                    | 4/26                     | 4/26                     |
| <b>PDR2 Written Report</b>            | 4/26                    | 4/26                    | 5/3                      | <b>5/11</b>              |
| <b>NASA/USRA Presentation</b>         | 5/3                     | <b>5/7</b>              | 5/3                      | <b>5/7</b>               |

NOTE : The tasks and dates in bold font represent changes to the original project schedule.

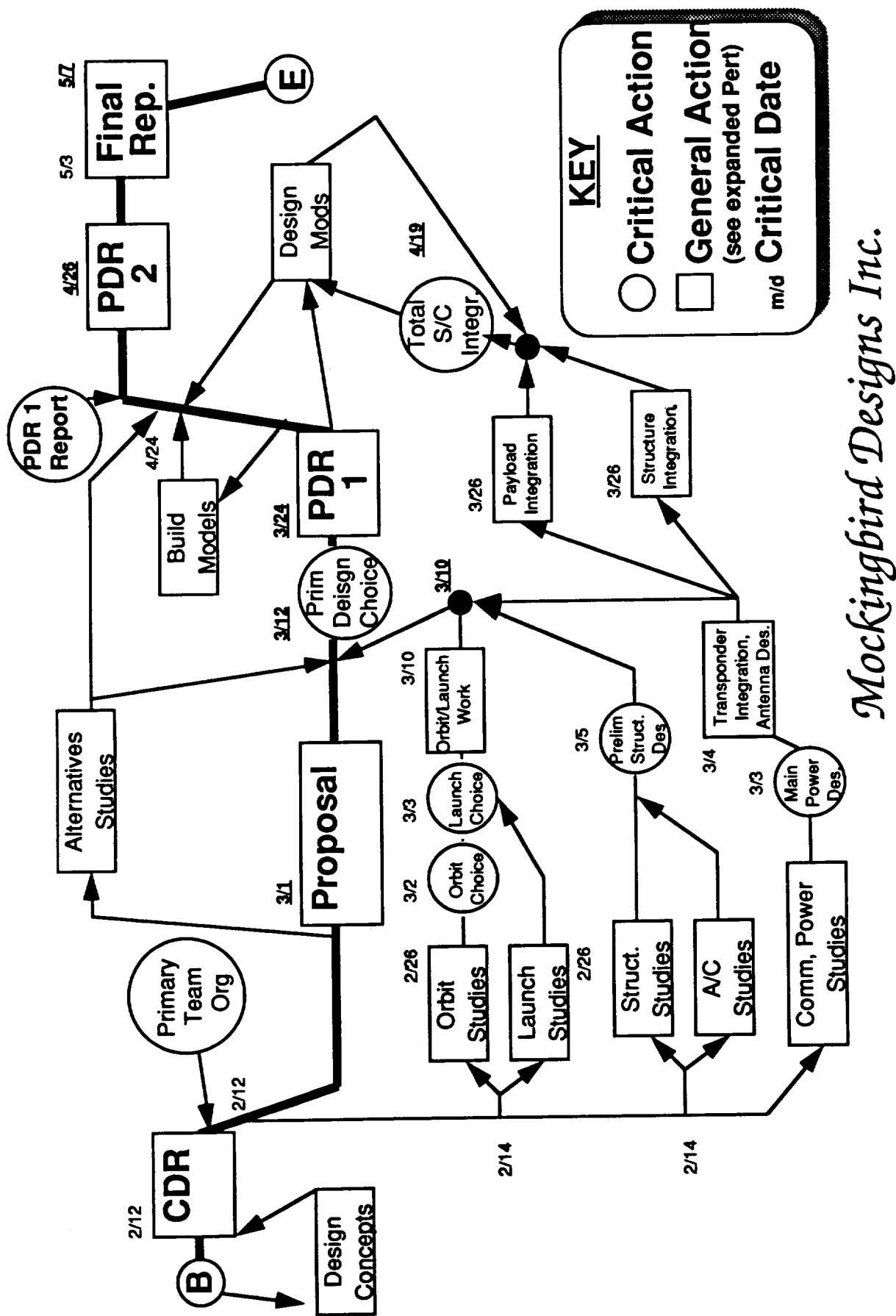


Figure 6.2 : Pert Chart for BATSAT Project.

# Mockingbird Designs Inc. The BATSAT Project

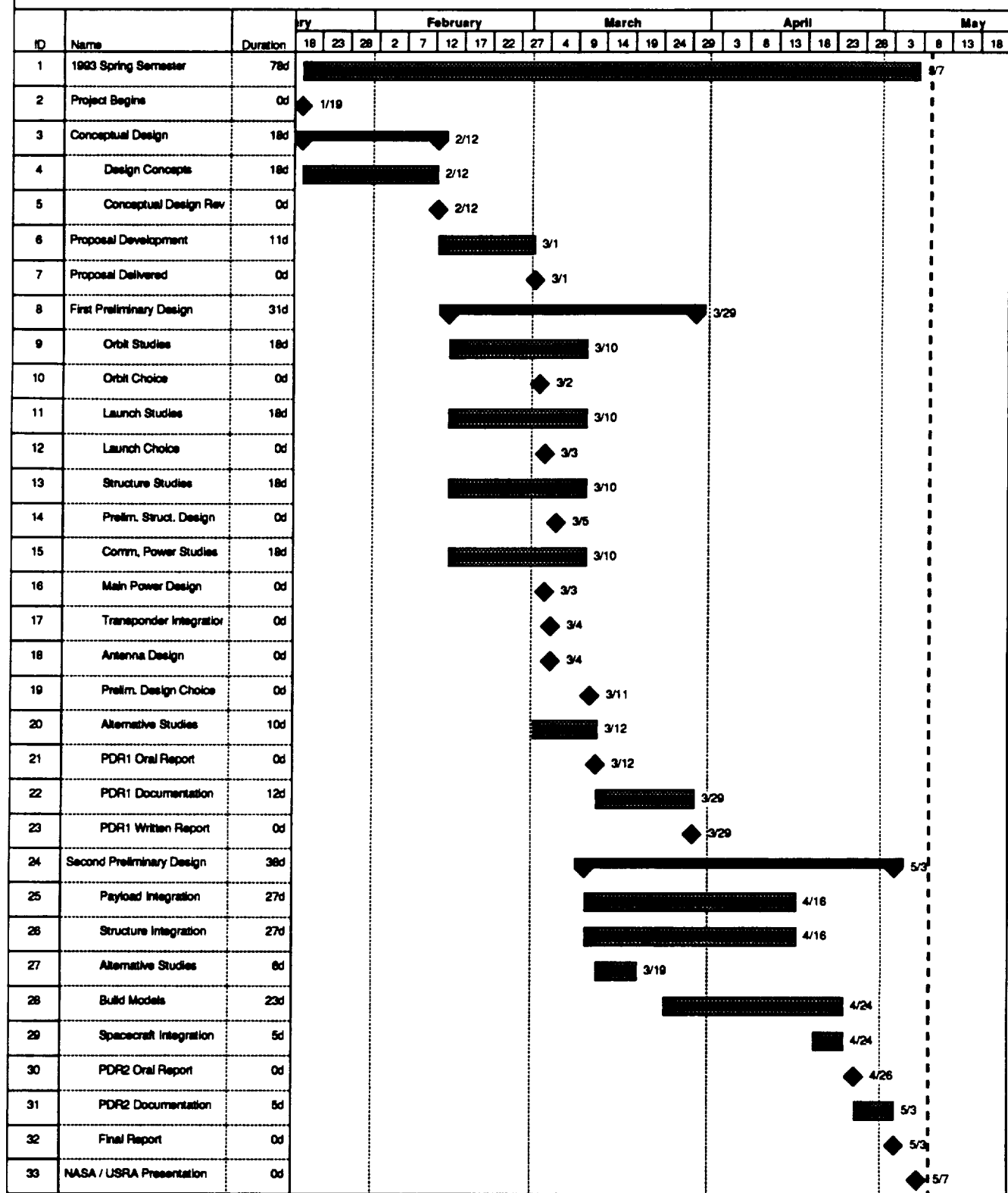


Figure 6.3: Gantt Chart for BATSAT project.

## **6.5 Project Integration**

The integration scheme for the BATSAT was different from previous projects. Due to the strong communication link between subsystems, BATSAT could be designed with integration in mind. From the beginning of the design of a subsystem, a subsystem leader would consult with other subsystem leaders who would give constraints based on their subsystem. Therefore the satellite was integrated throughout the design. However, an integration period was still required to provide a final check to the design to make sure all subsystems were compatible with each other. This was performed during integration meetings during the time period shown on the PERT chart. All team members would attend the integration meetings. The Program Manager identified components and systems that had common bonds, and the subsystem leaders would check compatibility.

## **6.6 Production Cost Estimates**

Mockingbird Designs had originally planned to do a detailed cost analysis using cost estimation relationship models. These models can be used to estimate subsystem costs through an equation based upon a certain parameter. For example, satellite structure costs are computed by using an equation that relates structure mass to cost. These equations, or CER's, are based on historical data collected over many different satellite projects and cover all subsystems, development and personnel costs, and even software and mission-ops costs. Parametric cost equations are usually exponential curve fits based on this historical data.

Mockingbird conducted an initial cost estimate using a cost analysis model found in Wertz and Larson [Ch. 20]. This model was based on the USAF Unmanned Spacecraft Model [Wertz and Larson, 663] historical data. However, the results of the model did not offer a realistic estimate of BATSAT's cost. This happened for several reasons. First, most BATSAT subsystems did not fall in the applicable range of the parametric equations, or CER's. Also, the cost model assumed normal commercial production and purchasing guidelines. Since BATSAT will be produced using student design and testing with university support, costs will be much lower. Finally, the cost model used was based upon large, complex satellite systems and does not take into account the simplicity and small size of the BATSAT satellite. A more accurate cost model would have used CER's based upon small satellite systems.

In order to get a feel of the satellite production costs, Mockingbird studied several other small satellite programs. Several universities have built small satellite systems at low costs. The OSCAR, GLOMR, and Microsat were all developed using student support and had production costs (not including ground segment costs) of under \$300,000 [Wertz and Larson:732]. Since most of the communications hardware needed by BATSAT has been designed by Caltech, and the structure will be built and tested by a university, Mockingbird believes that the total satellite production and testing costs (excluding launch) will fall well below \$200,000. By seeking off the shelf, outdated components for donation, the cost of the program could again be decreased significantly. Using student design courses for production, management, and testing will also greatly reduce personnel costs.

## 6.7 Project Costs

Figure 6.4 plots the total estimated and actual project costs throughout the project. Figures 6.5 and 6.6 show the associated personnel costs and material costs, respectively. The project costs varied above and below the straight line projected costs shown in the cost plot. The increase in weekly costs were usually associated with due dates throughout the design. As shown by the plot, the total project cost is \$22,714. Most of this cost is estimated personnel costs based on the GS pay scale. However, since the personnel were students the actual cost of this project primarily included material costs of around \$300.

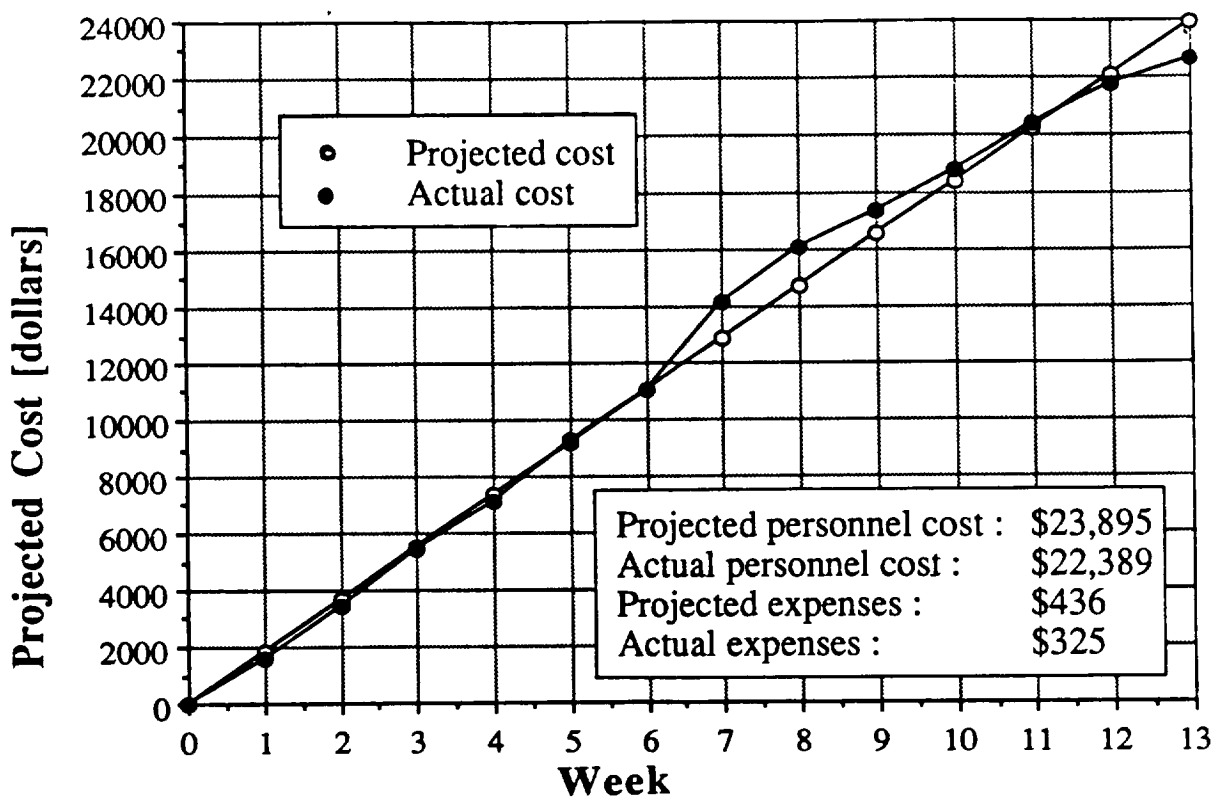


Figure 6.4: Cost of BATSAT Design

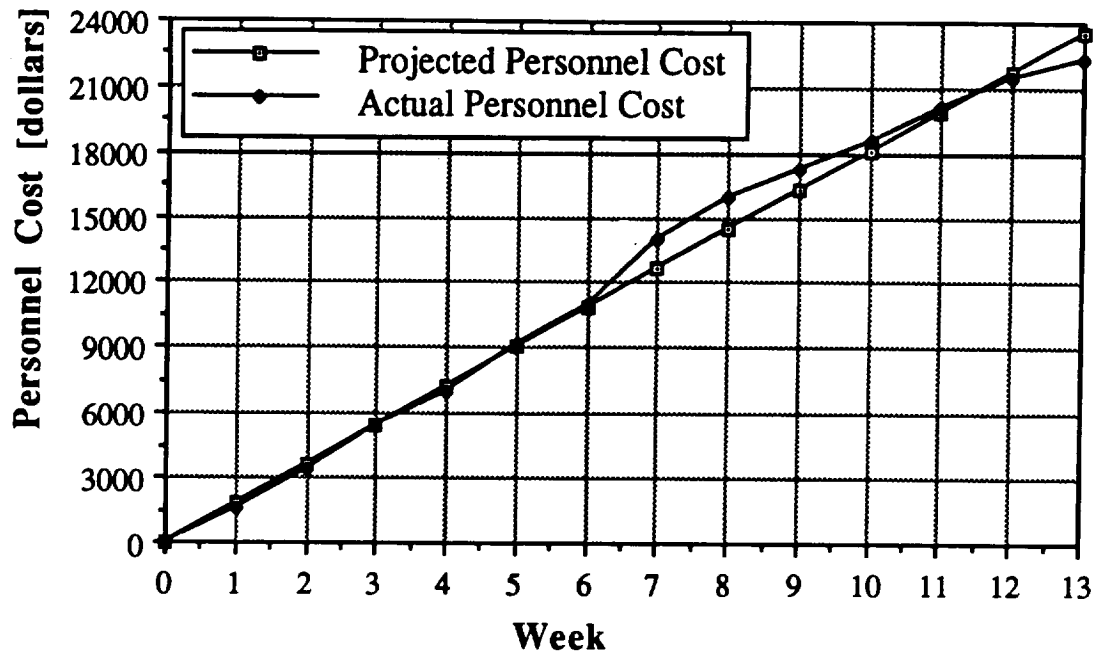


Figure 6.5: Personnel costs of BATSAT design

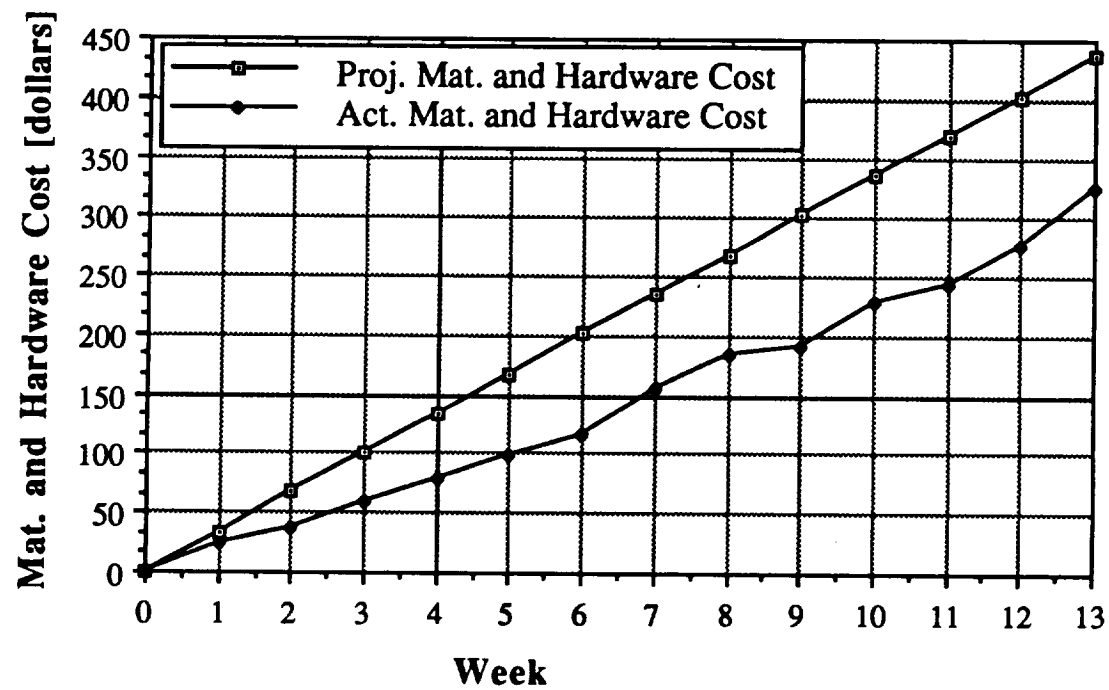


Figure 6.6: Material costs for BATSAT project.

## **7.0 RECOMMENDATIONS AND CONCLUSIONS**

Mockingbird Designs' main goal is to have the BATSAT satellite built by a university design team. Mockingbird feels that the Aerospace Labs at the University of Texas at Austin offer an excellent environment for satellite construction. The Mockingbird team hopes that the BATSAT design process will continue in the classroom and move into the structures laboratory. By combining the USRA Spacecraft design course with the Structural Testing course, the BATSAT satellite could easily be built by the University using undergraduate design. Mockingbird has already spoken to the head of the Structural Design and Testing lab, and the BATSAT satellite may become a senior design topic in the course.

Mockingbird feels that the first step in continuing the satellite project is to begin acquiring and building satellite components and the satellite structure. Members of the USRA have offered to help the University obtain satellite components from excess NASA inventory. Mockingbird hopes to initially secure a peak power tracker, thermal heaters, and silicon solar cells from NASA surplus. As mentioned previously, the SURFSAT design team has already built much of the communication hardware. Mockingbird hopes to begin dialogue with Caltech to try and integrate different aspects of the SURFSAT design with the BATSAT design.

As stated earlier, Mockingbird has already built part of the truss structure as a proof of concept exercise. Mockingbird hopes to simplify production of the satellite by modifying the design. By consulting with the Mechanical Engineering Department at the University, Mockingbird hopes to improve the manufacturability of the spacecraft. By making the structure as generic as possible, other missions could more easily be



adapted to the BATSAT design. Mockingbird hopes that these recommendations are acted upon quickly so that the current design team can help in the transition.

The current strain on satellite transmission speeds makes increasing data transmission rates for satellites an important mission. Whether Ka-Band transmissions will offer the needed speed is still unknown, but Mockingbird is confident that BATSAT will provide a wealth of information to help answer this question. Mockingbird Designs feels that the future of the space industry lies in small satellites. The BATSAT design, although designed for a specific mission, reveals many of the benefits of small satellites. By making space applications economically viable for more commercial enterprises, more uses will be exploited and mankind will move more quickly to the skies.

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## **Appendix A**

### **FORTRAN Program MODIFY**

# program modify

\*-----  
 \* This program creates a NASTRAN input file for the BATSAT structure  
 \* given the parameters:  
 \*

\* L - Primary length of circumferential element  
 \* r - Inner center element length  
 \* d - distance from L to r  
 \*

\* (Written by Michael J. Wortman, 4-20-93)  
 \*-----

```
double precision L,r,d,theta,grid,g,x,a
dimension grid(110,3),g(18,3),x(18,3)
```

```
open(11,file='mod8.dat',status='unknown')
```

\* Write preliminary NASTRAN data  
 \*

```
write(11,*)'NASTRAN SYSTEM(5)=39'
write(11,*)'ID STATICS,TEST'
write(11,*)'SOL 24'
write(11,*)'TIME 3'
write(11,*)'CEND'
write(11,*)'TITLE=ASE274 - MODEL 1'
write(11,*)'SUBTITLE=MODEL 1 STATIC'
write(11,*)'DISP=ALL'
write(11,*)'ELFORCE=ALL'
write(11,*)'ELSTRESS=ALL'
write(11,*)'LOAD=500'
write(11,*)'OLOAD=ALL'
write(11,*)'SUBCASE 1'
write(11,*)'SPC=102'
write(11,*)'OUTPUT(PLOT)'
write(11,*)'PLOTTER NAST'
write(11,*)'SET 1=ALL'
write(11,*)'AXES X,Y,Z'
write(11,*)'VIEW 0.,0.,0.'
write(11,*)'FIND SCALE,ORIGIN 1,SET 1'
write(11,*)'PLOT SET 1,ORIGIN 1,LABEL BOTH'
write(11,*)'PLOT STATIC DEFORMATION 0, SET 1, ORIGIN 1, LABEL
+BOTH'
write(11,*)'$L= ',L
write(11,*)'$r= ',r
write(11,*)'$d= ',d
write(11,*)'$theta= ',theta
write(11,*)'BEGIN BULK'
write(11,*)'$1.....2.....3.....4.....5.....6.....7.
+.....8.....9.....10'
write(11,120) 1,10,13,1,0.0,0.0,1.0
write(11,120) 2,10,16,6,0.0,0.0,1.0
write(11,120) 3,10,6,10,0.0,0.0,1.0
write(11,120) 4,10,10,20,0.0,0.0,1.0
write(11,120) 5,10,20,24,0.0,0.0,1.0
write(11,120) 6,10,24,28,0.0,0.0,1.0
write(11,120) 7,10,28,30,0.0,0.0,1.0
write(11,120) 8,10,14,5,0.0,0.0,1.0
write(11,120) 9,10,5,9,0.0,0.0,1.0
write(11,120) 10,10,9,18,0.0,0.0,1.0
write(11,120) 11,10,18,22,0.0,0.0,1.0
write(11,120) 12,10,22,26,0.0,0.0,1.0
write(11,120) 13,10,26,30,0.0,0.0,1.0
write(11,120) 14,10,13,2,0.0,0.0,1.0
write(11,120) 15,10,17,7,1.0,0.0,0.0
write(11,120) 16,10,7,11,1.0,0.0,0.0
```

```

write(11,120) 17,10,11,21,1.0,0.0,0.0
write(11,120) 18,10,21,25,1.0,0.0,0.0
write(11,120) 19,10,25,29,1.0,0.0,0.0
write(11,120) 20,10,29,30,1.0,0.0,0.0
write(11,120) 21,10,15,8,1.0,0.0,0.0
write(11,120) 22,10,8,12,1.0,0.0,0.0
write(11,120) 23,10,12,19,1.0,0.0,0.0
write(11,120) 24,10,19,23,1.0,0.0,0.0
write(11,120) 25,10,23,27,1.0,0.0,0.0
write(11,120) 26,10,27,30,1.0,0.0,0.0
write(11,120) 27,10,1,14,0.0,0.0,1.0
write(11,120) 28,10,3,15,0.0,0.0,1.0
write(11,120) 29,10,2,16,0.0,0.0,1.0
write(11,120) 30,10,4,17,1.0,0.0,0.0
write(11,120) 31,10,1,31,0.0,0.0,1.0
write(11,120) 32,10,31,35,0.0,0.0,1.0
write(11,120) 33,10,35,26,0.0,0.0,1.0
write(11,120) 34,10,31,9,0.0,0.0,1.0
write(11,120) 35,10,35,18,0.0,0.0,1.0
write(11,120) 36,10,3,32,1.0,0.0,0.0
write(11,120) 37,10,32,36,1.0,0.0,0.0
write(11,120) 38,10,36,27,1.0,0.0,0.0
write(11,120) 39,10,32,12,1.0,0.0,0.0
write(11,120) 40,10,36,19,1.0,0.0,0.0
write(11,120) 41,10,2,33,0.0,0.0,1.0
write(11,120) 42,10,33,37,0.0,0.0,1.0
write(11,120) 43,10,37,28,0.0,0.0,1.0
write(11,120) 44,10,33,10,0.0,0.0,1.0
write(11,120) 45,10,37,20,0.0,0.0,1.0
write(11,120) 46,10,4,34,1.0,0.0,0.0
write(11,120) 47,10,34,38,1.0,0.0,0.0
write(11,120) 48,10,38,29,1.0,0.0,0.0
write(11,120) 49,10,34,11,1.0,0.0,0.0
write(11,120) 50,10,38,21,1.0,0.0,0.0
write(11,120) 51,10,13,3,1.0,0.0,0.0
write(11,120) 52,10,13,4,1.0,0.0,0.0
write(11,*) '$'
+ write(11,*) 'GRAV      100          83.3      0.0      0.0
-1.0'
+ write(11,*) 'GRAV      200          34.3      1.0      0.0
0.0'
+ write(11,*) '$'
+ write(11,*) '$1.....2.....3.....4.....5.....6.....7.
+.....8.....9.....10'

```

```

*
* Determine grid points
*

```

```

print*, 'Primary length (L) = '
read*, L
print*, 'Inner Length (R) = '
read*, r
print*, 'Distance between L and R = '
read*, d

```

```

a=2*acos(-1.)/12

```

```

g(1,1)=L/2.
g(1,3)=0.
g(2,1)=L/2+L/2*cos(a)
g(2,3)=L/2*sin(a)
g(3,1)=L/2+L*cos(a)
g(3,3)=L*sin(a)
g(4,1)=g(3,1)+L*cos(2*a)
g(4,3)=g(3,3)+L*sin(2*a)
g(5,1)=g(4,1)
g(5,3)=g(4,3)+L

```

```

      g(6,1)=g(3,1)
      g(6,3)=g(5,3)+L*cos(a)
      g(7,1)=g(1,1)
      g(7,3)=g(6,3)+L*cos(2*a)
      g(8,1)=g(5,1)-d
      g(8,3)=g(7,3)/2+r/2
      g(9,1)=g(4,1)-d
      g(9,3)=g(7,3)/2-r/2

      do 10 i=10,18
         g(i,1)=-g(i-9,1)
         g(i,3)=g(i-9,3)
10      continue

      do 15 i=1,18
         g(i,2)=0.
15      continue

      do 20 i=1,18
         grid(i,1)=g(i,1)
         grid(i,2)=g(i,2)
         grid(i,3)=g(i,3)
20      continue
*
* Rotation loop
*
      j=0
      theta=0.

100     j=j+1
      theta=theta+acos(-1.)/6
      call rotate(g,theta,x)

      do 25 i=1,18
         grid(i+18*j,1)=x(i,1)
         grid(i+18*j,2)=x(i,2)
         grid(i+18*j,3)=x(i,3)
25      continue

      if(j.ne.5)go to 100
*
* Write results.
*
      do 30 i=1,108
         write(11,130) i,grid(i,1),grid(i,2),grid(i,3)
30      continue

      write(11,130) 109,0.,0.,0.
      write(11,130) 110,0.,0.,grid(7,3)
*
* Finish final section of file.
*
      write(11,*)'$'
      write(11,*)'$1.....2.....3.....4.....5.....6.....7.
+.....8.....9.....10'
      write(11,*) '$'
      write(11,*) 'LOAD      500      1.0      1.0      100'
      write(11,*) 'MAT1      20       70.0E9   26.0E9   0.33      2700.0  23
+0.0E-6'
      write(11,*) 'PBAR      10       20       7.07E-4  3.98E-8  3.98E-8  7.
+95E-8'
      write(11,*) 'SPC1      102'
      write(11,*) 'PARAM     COUPMASS1'
      write(11,*) 'PARAM     GRDPNT  0'
      write(11,*) 'PARAM     USETPRT  1'
      write(11,*) 'ENDDATA'

```

```

120    format(1x,'CBAR',t10,i2,t18,i2,t26,i2,t34,i2,t42,f3.1,t50,f3.1,t58,
+      f3.1)
130    format(1x,'GRID',t10,i3,t25,f8.4,t33,f8.4,t41,f8.4)

      stop
      end

*-----
*-----
      subroutine rotate(p,beta,q)
      double precision beta,p,q
      dimension p(18,3),q(18,3)
*
* This subroutine computes a plane of grid points by rotating a given
* set of points in the x-z plane by the angle beta.
*
      do 10 i=1,18
          q(i,1)=p(i,1)*cos(beta)+p(i,2)*sin(beta)
          q(i,2)=-p(i,1)*sin(beta)+p(i,2)*cos(beta)
          q(i,3)=p(i,3)
10      continue

      return
      end

```



## **Appendix A, cont.**

### **NASTRAN Static Model Listing**

```

NASTRAN
ID STATICS,TEST
SOL 101
TIME 3
CEND
TITLE=BATSAT STRUCTURE
SUBTITLE=SIDE VIEW PANEL STRESSES (MOD14)
DISP=ALL
ELFORCE=ALL
ELSTRESS=ALL
LOAD=500
OLOAD=ALL
SUBCASE 1
SPC=102
OUTPUT(PLOT)
PLOTTER NAST
SET 1=QUAD4,TRIA3
AXES MY,X,Z
VIEW 0.,0.,0.
FIND SCALE,ORIGIN 1,SET 1
CONTOUR MAJPRIN,EVEN 6,MAX,COMMON
PLOT SET 1,ORIGIN 1,LABEL BOTH
PLOT CONTOUR,SET 1,SHAPE
BEGIN BULK
$
$L= .1686m      r= .26m      d= .05m      diameter =0.62923m
$1.....2.....3.....4.....5.....6.....7.....8.....9.....10
$
CBAR    1      10      1      2      0.0000  1.0000  0.0000
CBAR    2      10      2      3      0.0000  1.0000  0.0000
CBAR    3      10      3      4      0.0000  1.0000  0.0000
CBAR    4      10      4      5      0.0000  1.0000  0.0000
CBAR    5      10      5      6      0.0000  1.0000  0.0000
CBAR    6      10      6      7      0.0000  1.0000  0.0000
CBAR    7      10      7      8      0.0000  1.0000  0.0000
CBAR    8      10      8      9      0.0000  1.0000  0.0000
CBAR    9      10      9      1      0.0000  1.0000  0.0000
CBAR   10      10      8      5      0.0000  1.0000  0.0000
CBAR   11      10      9      4      0.0000  1.0000  0.0000
CBAR   12      10     10     11      0.0000  1.0000  0.0000
CBAR   13      10     11     12      0.0000  1.0000  0.0000
CBAR   14      10     12     13      0.0000  1.0000  0.0000
CBAR   15      10     13     14      0.0000  1.0000  0.0000
CBAR   16      10     14     15      0.0000  1.0000  0.0000
CBAR   17      10     15     16      0.0000  1.0000  0.0000
CBAR   18      10     16     17      0.0000  1.0000  0.0000
CBAR   19      10     17     18      0.0000  1.0000  0.0000
CBAR   20      10     18     10      0.0000  1.0000  0.0000
CBAR   21      10     17     14      0.0000  1.0000  0.0000
CBAR   22      10     18     13      0.0000  1.0000  0.0000
CBAR   23      10      1    109      0.0000  1.0000  0.0000
CBAR   24      10     10   109      0.0000  1.0000  0.0000
CBAR   25      10      7   110      0.0000  1.0000  0.0000
CBAR   26      10     16   110      0.0000  1.0000  0.0000
CBAR   27      10     19     20     -0.5000  0.8660  0.0000
CBAR   28      10     20     21     -0.5000  0.8660  0.0000
CBAR   29      10     21     22     -0.5000  0.8660  0.0000
CBAR   30      10     22     23     -0.5000  0.8660  0.0000
CBAR   31      10     23     24     -0.5000  0.8660  0.0000
CBAR   32      10     24     25     -0.5000  0.8660  0.0000
CBAR   33      10     25     26     -0.5000  0.8660  0.0000
CBAR   34      10     26     27     -0.5000  0.8660  0.0000
CBAR   35      10     27     19     -0.5000  0.8660  0.0000
CBAR   36      10     26     23     -0.5000  0.8660  0.0000
CBAR   37      10     27     22     -0.5000  0.8660  0.0000
CBAR   38      10     28     29     -0.5000  0.8660  0.0000
CBAR   39      10     29     30     -0.5000  0.8660  0.0000

```

|      |     |    |    |     |         |         |        |
|------|-----|----|----|-----|---------|---------|--------|
| CBAR | 40  | 10 | 30 | 31  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 41  | 10 | 31 | 32  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 42  | 10 | 32 | 33  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 43  | 10 | 33 | 34  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 44  | 10 | 34 | 35  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 45  | 10 | 35 | 36  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 46  | 10 | 36 | 28  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 47  | 10 | 35 | 32  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 48  | 10 | 36 | 31  | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 49  | 10 | 19 | 109 | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 50  | 10 | 28 | 109 | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 51  | 10 | 25 | 110 | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 52  | 10 | 34 | 110 | -0.5000 | 0.8660  | 0.0000 |
| CBAR | 53  | 10 | 37 | 38  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 54  | 10 | 38 | 39  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 55  | 10 | 39 | 40  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 56  | 10 | 40 | 41  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 57  | 10 | 41 | 42  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 58  | 10 | 42 | 43  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 59  | 10 | 43 | 44  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 60  | 10 | 44 | 45  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 61  | 10 | 45 | 37  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 62  | 10 | 44 | 41  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 63  | 10 | 45 | 40  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 64  | 10 | 46 | 47  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 65  | 10 | 47 | 48  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 66  | 10 | 48 | 49  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 67  | 10 | 49 | 50  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 68  | 10 | 50 | 51  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 69  | 10 | 51 | 52  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 70  | 10 | 52 | 53  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 71  | 10 | 53 | 54  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 72  | 10 | 54 | 46  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 73  | 10 | 53 | 50  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 74  | 10 | 54 | 49  | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 75  | 10 | 37 | 109 | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 76  | 10 | 46 | 109 | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 77  | 10 | 43 | 110 | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 78  | 10 | 52 | 110 | -0.8660 | 0.5000  | 0.0000 |
| CBAR | 79  | 10 | 55 | 56  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 80  | 10 | 56 | 57  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 81  | 10 | 57 | 58  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 82  | 10 | 58 | 59  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 83  | 10 | 59 | 60  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 84  | 10 | 60 | 61  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 85  | 10 | 61 | 62  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 86  | 10 | 62 | 63  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 87  | 10 | 63 | 55  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 88  | 10 | 62 | 59  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 89  | 10 | 63 | 58  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 90  | 10 | 64 | 65  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 91  | 10 | 65 | 66  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 92  | 10 | 66 | 67  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 93  | 10 | 67 | 68  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 94  | 10 | 68 | 69  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 95  | 10 | 69 | 70  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 96  | 10 | 70 | 71  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 97  | 10 | 71 | 72  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 98  | 10 | 72 | 64  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 99  | 10 | 71 | 68  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 100 | 10 | 72 | 67  | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 101 | 10 | 55 | 109 | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 102 | 10 | 64 | 109 | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 103 | 10 | 61 | 110 | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 104 | 10 | 70 | 110 | -1.0000 | 0.0000  | 0.0000 |
| CBAR | 105 | 10 | 73 | 74  | -0.8660 | -0.5000 | 0.0000 |

|      |     |    |     |     |         |         |        |
|------|-----|----|-----|-----|---------|---------|--------|
| CBAR | 106 | 10 | 74  | 75  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 107 | 10 | 75  | 76  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 108 | 10 | 76  | 77  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 109 | 10 | 77  | 78  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 110 | 10 | 78  | 79  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 111 | 10 | 79  | 80  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 112 | 10 | 80  | 81  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 113 | 10 | 81  | 73  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 114 | 10 | 80  | 77  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 115 | 10 | 81  | 76  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 116 | 10 | 82  | 83  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 117 | 10 | 83  | 84  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 118 | 10 | 84  | 85  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 119 | 10 | 85  | 86  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 120 | 10 | 86  | 87  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 121 | 10 | 87  | 88  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 122 | 10 | 88  | 89  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 123 | 10 | 89  | 90  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 124 | 10 | 90  | 82  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 125 | 10 | 89  | 86  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 126 | 10 | 90  | 85  | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 127 | 10 | 73  | 109 | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 128 | 10 | 82  | 109 | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 129 | 10 | 79  | 110 | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 130 | 10 | 88  | 110 | -0.8660 | -0.5000 | 0.0000 |
| CBAR | 131 | 10 | 91  | 92  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 132 | 10 | 92  | 93  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 133 | 10 | 93  | 94  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 134 | 10 | 94  | 95  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 135 | 10 | 95  | 96  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 136 | 10 | 96  | 97  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 137 | 10 | 97  | 98  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 138 | 10 | 98  | 99  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 139 | 10 | 99  | 91  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 140 | 10 | 98  | 95  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 141 | 10 | 99  | 94  | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 142 | 10 | 100 | 101 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 143 | 10 | 101 | 102 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 144 | 10 | 102 | 103 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 145 | 10 | 103 | 104 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 146 | 10 | 104 | 105 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 147 | 10 | 105 | 106 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 148 | 10 | 106 | 107 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 149 | 10 | 107 | 108 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 150 | 10 | 108 | 100 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 151 | 10 | 107 | 104 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 152 | 10 | 108 | 103 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 153 | 10 | 91  | 109 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 154 | 10 | 100 | 109 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 155 | 10 | 97  | 110 | -0.5000 | -0.8660 | 0.0000 |
| CBAR | 156 | 10 | 106 | 110 | -0.5000 | -0.8660 | 0.0000 |
| \$   |     |    |     |     |         |         |        |
| \$   |     |    |     |     |         |         |        |
| \$   |     |    |     |     |         |         |        |
| CBAR | 157 | 20 | 4   | 22  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 158 | 20 | 22  | 40  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 159 | 20 | 40  | 58  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 160 | 20 | 58  | 76  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 161 | 20 | 76  | 94  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 162 | 20 | 94  | 13  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 163 | 20 | 13  | 31  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 164 | 20 | 31  | 49  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 165 | 20 | 49  | 67  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 166 | 20 | 67  | 85  | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 167 | 20 | 85  | 103 | 0.0000  | 0.0000  | 1.0000 |
| CBAR | 168 | 20 | 103 | 4   | 0.0000  | 0.0000  | 1.0000 |

|      |     |    |     |     |        |        |        |
|------|-----|----|-----|-----|--------|--------|--------|
| \$   |     |    |     |     |        |        |        |
| CBAR | 169 | 20 | 5   | 23  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 170 | 20 | 23  | 41  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 171 | 20 | 41  | 59  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 172 | 20 | 59  | 77  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 173 | 20 | 77  | 95  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 174 | 20 | 95  | 14  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 175 | 20 | 14  | 32  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 176 | 20 | 32  | 50  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 177 | 20 | 50  | 68  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 178 | 20 | 68  | 86  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 179 | 20 | 86  | 104 | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 180 | 20 | 104 | 5   | 0.0000 | 0.0000 | 1.0000 |
| \$   |     |    |     |     |        |        |        |
| CBAR | 181 | 20 | 2   | 20  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 182 | 20 | 20  | 38  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 183 | 20 | 38  | 56  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 184 | 20 | 56  | 74  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 185 | 20 | 74  | 92  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 186 | 20 | 92  | 11  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 187 | 20 | 11  | 29  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 188 | 20 | 29  | 47  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 189 | 20 | 47  | 65  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 190 | 20 | 65  | 83  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 191 | 20 | 83  | 101 | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 192 | 20 | 101 | 2   | 0.0000 | 0.0000 | 1.0000 |
| \$   |     |    |     |     |        |        |        |
| CBAR | 193 | 20 | 1   | 19  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 194 | 20 | 19  | 37  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 195 | 20 | 37  | 55  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 196 | 20 | 55  | 73  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 197 | 20 | 73  | 91  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 198 | 20 | 91  | 10  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 199 | 20 | 10  | 28  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 200 | 20 | 28  | 46  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 201 | 20 | 46  | 64  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 202 | 20 | 64  | 82  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 203 | 20 | 82  | 100 | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 204 | 20 | 100 | 1   | 0.0000 | 0.0000 | 1.0000 |
| \$   |     |    |     |     |        |        |        |
| CBAR | 205 | 20 | 3   | 21  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 206 | 20 | 21  | 39  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 207 | 20 | 39  | 57  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 208 | 20 | 57  | 75  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 209 | 20 | 75  | 93  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 210 | 20 | 93  | 12  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 211 | 20 | 12  | 30  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 212 | 20 | 30  | 48  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 213 | 20 | 48  | 66  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 214 | 20 | 66  | 84  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 215 | 20 | 84  | 102 | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 216 | 20 | 102 | 3   | 0.0000 | 0.0000 | 1.0000 |
| \$   |     |    |     |     |        |        |        |
| CBAR | 217 | 20 | 6   | 24  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 218 | 20 | 24  | 42  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 219 | 20 | 42  | 60  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 220 | 20 | 60  | 78  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 221 | 20 | 78  | 96  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 222 | 20 | 96  | 15  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 223 | 20 | 15  | 33  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 224 | 20 | 33  | 51  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 225 | 20 | 51  | 69  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 226 | 20 | 69  | 87  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 227 | 20 | 87  | 105 | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 228 | 20 | 105 | 6   | 0.0000 | 0.0000 | 1.0000 |
| \$   |     |    |     |     |        |        |        |

|      |     |    |     |     |        |        |        |
|------|-----|----|-----|-----|--------|--------|--------|
| CBAR | 229 | 20 | 7   | 25  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 230 | 20 | 25  | 43  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 231 | 20 | 43  | 61  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 232 | 20 | 61  | 79  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 233 | 20 | 79  | 97  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 234 | 20 | 97  | 16  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 235 | 20 | 16  | 34  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 236 | 20 | 34  | 52  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 237 | 20 | 52  | 70  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 238 | 20 | 70  | 88  | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 239 | 20 | 88  | 106 | 0.0000 | 0.0000 | 1.0000 |
| CBAR | 240 | 20 | 106 | 7   | 0.0000 | 0.0000 | 1.0000 |

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|        |     |    |   |    |    |   |
|--------|-----|----|---|----|----|---|
| CQUAD4 | 241 | 30 | 1 | 19 | 20 | 2 |
| CQUAD4 | 242 | 30 | 2 | 20 | 21 | 3 |
| CQUAD4 | 243 | 30 | 3 | 21 | 22 | 4 |
| CQUAD4 | 244 | 30 | 4 | 22 | 23 | 5 |
| CQUAD4 | 245 | 30 | 5 | 23 | 24 | 6 |
| CQUAD4 | 246 | 30 | 6 | 24 | 25 | 7 |

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|        |     |    |    |    |    |    |
|--------|-----|----|----|----|----|----|
| CQUAD4 | 247 | 30 | 10 | 28 | 29 | 11 |
| CQUAD4 | 248 | 30 | 11 | 29 | 30 | 12 |
| CQUAD4 | 249 | 30 | 12 | 30 | 31 | 13 |
| CQUAD4 | 250 | 30 | 13 | 31 | 32 | 14 |
| CQUAD4 | 251 | 30 | 14 | 32 | 33 | 15 |
| CQUAD4 | 252 | 30 | 15 | 33 | 34 | 16 |

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|        |     |    |    |    |    |    |
|--------|-----|----|----|----|----|----|
| CQUAD4 | 253 | 30 | 19 | 37 | 38 | 20 |
| CQUAD4 | 254 | 30 | 20 | 38 | 39 | 21 |
| CQUAD4 | 255 | 30 | 21 | 39 | 40 | 22 |
| CQUAD4 | 256 | 30 | 22 | 40 | 41 | 23 |
| CQUAD4 | 257 | 30 | 23 | 41 | 42 | 24 |
| CQUAD4 | 258 | 30 | 24 | 42 | 43 | 25 |

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|        |     |    |    |    |    |    |
|--------|-----|----|----|----|----|----|
| CQUAD4 | 259 | 30 | 28 | 46 | 47 | 29 |
| CQUAD4 | 260 | 30 | 29 | 47 | 48 | 30 |
| CQUAD4 | 261 | 30 | 30 | 48 | 49 | 31 |
| CQUAD4 | 262 | 30 | 31 | 49 | 50 | 32 |
| CQUAD4 | 263 | 30 | 32 | 50 | 51 | 33 |
| CQUAD4 | 264 | 30 | 33 | 51 | 52 | 34 |

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|        |     |    |    |    |    |    |
|--------|-----|----|----|----|----|----|
| CQUAD4 | 265 | 30 | 37 | 55 | 56 | 38 |
| CQUAD4 | 266 | 30 | 38 | 56 | 57 | 39 |
| CQUAD4 | 267 | 30 | 39 | 57 | 58 | 40 |
| CQUAD4 | 268 | 30 | 40 | 58 | 59 | 41 |
| CQUAD4 | 269 | 30 | 41 | 59 | 60 | 42 |
| CQUAD4 | 270 | 30 | 42 | 60 | 61 | 43 |

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|        |     |    |    |    |    |    |
|--------|-----|----|----|----|----|----|
| CQUAD4 | 271 | 30 | 46 | 64 | 65 | 47 |
| CQUAD4 | 272 | 30 | 47 | 65 | 66 | 48 |
| CQUAD4 | 273 | 30 | 48 | 66 | 67 | 49 |
| CQUAD4 | 274 | 30 | 49 | 67 | 68 | 50 |
| CQUAD4 | 275 | 30 | 50 | 68 | 69 | 51 |
| CQUAD4 | 276 | 30 | 51 | 69 | 70 | 52 |

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|        |     |    |    |    |    |    |
|--------|-----|----|----|----|----|----|
| CQUAD4 | 277 | 30 | 55 | 73 | 74 | 56 |
| CQUAD4 | 278 | 30 | 56 | 74 | 75 | 57 |
| CQUAD4 | 279 | 30 | 57 | 75 | 76 | 58 |
| CQUAD4 | 280 | 30 | 58 | 76 | 77 | 59 |
| CQUAD4 | 281 | 30 | 59 | 77 | 78 | 60 |
| CQUAD4 | 282 | 30 | 60 | 78 | 79 | 61 |

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|        |     |    |    |    |    |    |
|--------|-----|----|----|----|----|----|
| CQUAD4 | 283 | 30 | 64 | 82 | 83 | 65 |
|--------|-----|----|----|----|----|----|

|        |     |    |        |     |     |      |
|--------|-----|----|--------|-----|-----|------|
| CQUAD4 | 284 | 30 | 65     | 83  | 84  | 66   |
| CQUAD4 | 285 | 30 | 66     | 84  | 85  | 67   |
| CQUAD4 | 286 | 30 | 67     | 85  | 86  | 68   |
| CQUAD4 | 287 | 30 | 68     | 86  | 87  | 69   |
| CQUAD4 | 288 | 30 | 69     | 87  | 88  | 70   |
| \$     |     |    |        |     |     |      |
| CQUAD4 | 289 | 30 | 73     | 91  | 92  | 74   |
| CQUAD4 | 290 | 30 | 74     | 92  | 93  | 75   |
| CQUAD4 | 291 | 30 | 75     | 93  | 94  | 76   |
| CQUAD4 | 292 | 30 | 76     | 94  | 95  | 77   |
| CQUAD4 | 293 | 30 | 77     | 95  | 96  | 78   |
| CQUAD4 | 294 | 30 | 78     | 96  | 97  | 79   |
| \$     |     |    |        |     |     |      |
| CQUAD4 | 295 | 30 | 82     | 100 | 101 | 83   |
| CQUAD4 | 296 | 30 | 83     | 101 | 102 | 84   |
| CQUAD4 | 297 | 30 | 84     | 102 | 103 | 85   |
| CQUAD4 | 298 | 30 | 85     | 103 | 104 | 86   |
| CQUAD4 | 299 | 30 | 86     | 104 | 105 | 87   |
| CQUAD4 | 300 | 30 | 87     | 105 | 106 | 88   |
| \$     |     |    |        |     |     |      |
| CQUAD4 | 301 | 30 | 91     | 10  | 11  | 92   |
| CQUAD4 | 302 | 30 | 92     | 11  | 12  | 93   |
| CQUAD4 | 303 | 30 | 93     | 12  | 13  | 94   |
| CQUAD4 | 304 | 30 | 94     | 13  | 14  | 95   |
| CQUAD4 | 305 | 30 | 95     | 14  | 15  | 96   |
| CQUAD4 | 306 | 30 | 96     | 15  | 16  | 97   |
| \$     |     |    |        |     |     |      |
| CQUAD4 | 307 | 30 | 100    | 1   | 2   | 101  |
| CQUAD4 | 308 | 30 | 101    | 2   | 3   | 102  |
| CQUAD4 | 309 | 30 | 102    | 3   | 4   | 103  |
| CQUAD4 | 310 | 30 | 103    | 4   | 5   | 104  |
| CQUAD4 | 311 | 30 | 104    | 5   | 6   | 105  |
| CQUAD4 | 312 | 30 | 105    | 6   | 7   | 106  |
| \$     |     |    |        |     |     |      |
| \$     |     |    |        |     |     |      |
| CTRIA3 | 313 | 40 | 109    | 1   | 19  |      |
| CTRIA3 | 314 | 40 | 109    | 19  | 37  |      |
| CTRIA3 | 315 | 40 | 109    | 37  | 55  |      |
| CTRIA3 | 316 | 40 | 109    | 55  | 73  |      |
| CTRIA3 | 317 | 40 | 109    | 73  | 91  |      |
| CTRIA3 | 318 | 40 | 109    | 91  | 10  |      |
| CTRIA3 | 319 | 40 | 109    | 10  | 28  |      |
| CTRIA3 | 320 | 40 | 109    | 28  | 46  |      |
| CTRIA3 | 321 | 40 | 109    | 46  | 64  |      |
| CTRIA3 | 322 | 40 | 109    | 64  | 82  |      |
| CTRIA3 | 323 | 40 | 109    | 82  | 100 |      |
| CTRIA3 | 324 | 40 | 109    | 100 | 1   |      |
| \$     |     |    |        |     |     |      |
| CTRIA3 | 325 | 40 | 110    | 7   | 25  |      |
| CTRIA3 | 326 | 40 | 110    | 25  | 43  |      |
| CTRIA3 | 327 | 40 | 110    | 43  | 61  |      |
| CTRIA3 | 328 | 40 | 110    | 61  | 79  |      |
| CTRIA3 | 329 | 40 | 110    | 79  | 97  |      |
| CTRIA3 | 330 | 40 | 110    | 97  | 16  |      |
| CTRIA3 | 331 | 40 | 110    | 16  | 34  |      |
| CTRIA3 | 332 | 40 | 110    | 34  | 52  |      |
| CTRIA3 | 333 | 40 | 110    | 52  | 70  |      |
| CTRIA3 | 334 | 40 | 110    | 70  | 88  |      |
| CTRIA3 | 335 | 40 | 110    | 88  | 106 |      |
| CTRIA3 | 336 | 40 | 110    | 106 | 7   |      |
| \$     |     |    |        |     |     |      |
| \$     |     |    |        |     |     |      |
| GRAV   | 100 |    | 107.91 | 0.0 | 0.0 | -1.0 |
| GRAV   | 200 |    | 34.3   | 1.0 | 0.0 | 0.0  |
| \$     |     |    |        |     |     |      |

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|      |    |         |         |        |     |
|------|----|---------|---------|--------|-----|
| GRID | 1  | 0.0843  | 0.0000  | 0.0000 |     |
| GRID | 2  | 0.1574  | 0.0000  | 0.0422 | 123 |
| GRID | 3  | 0.2304  | 0.0000  | 0.0844 |     |
| GRID | 4  | 0.3148  | 0.0000  | 0.2304 |     |
| GRID | 5  | 0.3148  | 0.0000  | 0.3991 |     |
| GRID | 6  | 0.2304  | 0.0000  | 0.5452 |     |
| GRID | 7  | 0.0843  | 0.0000  | 0.6296 |     |
| GRID | 8  | 0.2648  | 0.0000  | 0.4448 |     |
| GRID | 9  | 0.2648  | 0.0000  | 0.1848 |     |
| GRID | 10 | -0.0843 | 0.0000  | 0.0000 |     |
| GRID | 11 | -0.1574 | 0.0000  | 0.0422 | 123 |
| GRID | 12 | -0.2304 | 0.0000  | 0.0844 |     |
| GRID | 13 | -0.3148 | 0.0000  | 0.2304 |     |
| GRID | 14 | -0.3148 | 0.0000  | 0.3991 |     |
| GRID | 15 | -0.2304 | 0.0000  | 0.5452 |     |
| GRID | 16 | -0.0843 | 0.0000  | 0.6296 |     |
| GRID | 17 | -0.2648 | 0.0000  | 0.4448 |     |
| GRID | 18 | -0.2648 | 0.0000  | 0.1848 |     |
| GRID | 19 | 0.0730  | -0.0422 | 0.0000 |     |
| GRID | 20 | 0.1363  | -0.0787 | 0.0422 | 123 |
| GRID | 21 | 0.1996  | -0.1152 | 0.0844 |     |
| GRID | 22 | 0.2726  | -0.1574 | 0.2304 |     |
| GRID | 23 | 0.2726  | -0.1574 | 0.3991 |     |
| GRID | 24 | 0.1996  | -0.1152 | 0.5452 |     |
| GRID | 25 | 0.0730  | -0.0422 | 0.6296 |     |
| GRID | 26 | 0.2293  | -0.1324 | 0.4448 |     |
| GRID | 27 | 0.2293  | -0.1324 | 0.1848 |     |
| GRID | 28 | -0.0730 | 0.0422  | 0.0000 |     |
| GRID | 29 | -0.1363 | 0.0787  | 0.0422 | 123 |
| GRID | 30 | -0.1996 | 0.1152  | 0.0844 |     |
| GRID | 31 | -0.2726 | 0.1574  | 0.2304 |     |
| GRID | 32 | -0.2726 | 0.1574  | 0.3991 |     |
| GRID | 33 | -0.1996 | 0.1152  | 0.5452 |     |
| GRID | 34 | -0.0730 | 0.0422  | 0.6296 |     |
| GRID | 35 | -0.2293 | 0.1324  | 0.4448 |     |
| GRID | 36 | -0.2293 | 0.1324  | 0.1848 |     |
| GRID | 37 | 0.0422  | -0.0730 | 0.0000 |     |
| GRID | 38 | 0.0787  | -0.1363 | 0.0422 | 123 |
| GRID | 39 | 0.1152  | -0.1996 | 0.0844 |     |
| GRID | 40 | 0.1574  | -0.2726 | 0.2304 |     |
| GRID | 41 | 0.1574  | -0.2726 | 0.3991 |     |
| GRID | 42 | 0.1152  | -0.1996 | 0.5452 |     |
| GRID | 43 | 0.0422  | -0.0730 | 0.6296 |     |
| GRID | 44 | 0.1324  | -0.2293 | 0.4448 |     |
| GRID | 45 | 0.1324  | -0.2293 | 0.1848 |     |
| GRID | 46 | -0.0422 | 0.0730  | 0.0000 |     |
| GRID | 47 | -0.0787 | 0.1363  | 0.0422 | 123 |
| GRID | 48 | -0.1152 | 0.1996  | 0.0844 |     |
| GRID | 49 | -0.1574 | 0.2726  | 0.2304 |     |
| GRID | 50 | -0.1574 | 0.2726  | 0.3991 |     |
| GRID | 51 | -0.1152 | 0.1996  | 0.5452 |     |
| GRID | 52 | -0.0422 | 0.0730  | 0.6296 |     |
| GRID | 53 | -0.1324 | 0.2293  | 0.4448 |     |
| GRID | 54 | -0.1324 | 0.2293  | 0.1848 |     |
| GRID | 55 | 0.0000  | -0.0843 | 0.0000 |     |
| GRID | 56 | 0.0000  | -0.1574 | 0.0422 | 123 |
| GRID | 57 | 0.0000  | -0.2304 | 0.0844 |     |
| GRID | 58 | 0.0000  | -0.3148 | 0.2304 |     |
| GRID | 59 | 0.0000  | -0.3148 | 0.3991 |     |
| GRID | 60 | 0.0000  | -0.2304 | 0.5452 |     |
| GRID | 61 | 0.0000  | -0.0843 | 0.6296 |     |
| GRID | 62 | 0.0000  | -0.2648 | 0.4448 |     |
| GRID | 63 | 0.0000  | -0.2648 | 0.1848 |     |
| GRID | 64 | 0.0000  | 0.0843  | 0.0000 |     |
| GRID | 65 | 0.0000  | 0.1574  | 0.0422 | 123 |
| GRID | 66 | 0.0000  | 0.2304  | 0.0844 |     |



|  |           |        |                                  |         |                 |            |
|--|-----------|--------|----------------------------------|---------|-----------------|------------|
| GRID   | 67        |        | 0.0000                           | 0.3148  | 0.2304          |            |
| GRID   | 68        |        | 0.0000                           | 0.3148  | 0.3991          |            |
| GRID   | 69        |        | 0.0000                           | 0.2304  | 0.5452          |            |
| GRID   | 70        |        | 0.0000                           | 0.0843  | 0.6296          |            |
| GRID   | 71        |        | 0.0000                           | 0.2648  | 0.4448          |            |
| GRID   | 72        |        | 0.0000                           | 0.2648  | 0.1848          |            |
| GRID   | 73        |        | -0.0422                          | -0.0730 | 0.0000          |            |
| GRID   | 74        |        | -0.0787                          | -0.1363 | 0.0422          | 123        |
| GRID   | 75        |        | -0.1152                          | -0.1996 | 0.0844          |            |
| GRID   | 76        |        | -0.1574                          | -0.2726 | 0.2304          |            |
| GRID   | 77        |        | -0.1574                          | -0.2726 | 0.3991          |            |
| GRID   | 78        |        | -0.1152                          | -0.1996 | 0.5452          |            |
| GRID   | 79        |        | -0.0422                          | -0.0730 | 0.6296          |            |
| GRID   | 80        |        | -0.1324                          | -0.2293 | 0.4448          |            |
| GRID   | 81        |        | -0.1324                          | -0.2293 | 0.1848          |            |
| GRID   | 82        |        | 0.0422                           | 0.0730  | 0.0000          |            |
| GRID   | 83        |        | 0.0787                           | 0.1363  | 0.0422          | 123        |
| GRID   | 84        |        | 0.1152                           | 0.1996  | 0.0844          |            |
| GRID   | 85        |        | 0.1574                           | 0.2726  | 0.2304          |            |
| GRID   | 86        |        | 0.1574                           | 0.2726  | 0.3991          |            |
| GRID   | 87        |        | 0.1152                           | 0.1996  | 0.5452          |            |
| GRID   | 88        |        | 0.0422                           | 0.0730  | 0.6296          |            |
| GRID   | 89        |        | 0.1324                           | 0.2293  | 0.4448          |            |
| GRID   | 90        |        | 0.1324                           | 0.2293  | 0.1848          |            |
| GRID   | 91        |        | -0.0730                          | -0.0422 | 0.0000          |            |
| GRID   | 92        |        | -0.1363                          | -0.0787 | 0.0422          | 123        |
| GRID   | 93        |        | -0.1996                          | -0.1152 | 0.0844          |            |
| GRID   | 94        |        | -0.2726                          | -0.1574 | 0.2304          |            |
| GRID   | 95        |        | -0.2726                          | -0.1574 | 0.3991          |            |
| GRID   | 96        |        | -0.1996                          | -0.1152 | 0.5452          |            |
| GRID   | 97        |        | -0.0730                          | -0.0422 | 0.6296          |            |
| GRID   | 98        |        | -0.2293                          | -0.1324 | 0.4448          |            |
| GRID   | 99        |        | -0.2293                          | -0.1324 | 0.1848          |            |
| GRID   | 100       |        | 0.0730                           | 0.0422  | 0.0000          |            |
| GRID   | 101       |        | 0.1363                           | 0.0787  | 0.0422          | 123        |
| GRID   | 102       |        | 0.1996                           | 0.1152  | 0.0844          |            |
| GRID   | 103       |        | 0.2726                           | 0.1574  | 0.2304          |            |
| GRID   | 104       |        | 0.2726                           | 0.1574  | 0.3991          |            |
| GRID   | 105       |        | 0.1996                           | 0.1152  | 0.5452          |            |
| GRID   | 106       |        | 0.0730                           | 0.0422  | 0.6296          |            |
| GRID   | 107       |        | 0.2293                           | 0.1324  | 0.4448          |            |
| GRID   | 108       |        | 0.2293                           | 0.1324  | 0.1848          |            |
| GRID   | 109       |        | 0.0000                           | 0.0000  | 0.0000          |            |
| GRID   | 110       |        | 0.0000                           | 0.0000  | 0.6296          |            |
| \$   |           |        |                                  |         |                 |            |
| \$1.....2.....3.....4.....5.....6.....7.....8.....9.....10 |           |        |                                  |         |                 |            |
| \$   |           |        |                                  |         |                 |            |
| LOAD   | 500       | 1.0    | 1.0                              | 100     | 1.0             | 200        |
| MAT1   | 25        | 70.0+9 | 26.316+90.33                     |         | 2700.0          | 23.0-6     |
| PBAR   | 10        | 25     | 4.0323-51.355-101.355-108.130-10 |         |                 |            |
| PBAR   | 20        | 25     | 1.613-4                          | 8.671-9 | 5.420-106.121-9 |            |
| PSHELL   | 30        | 25     | .003                             | 25      | 1.0             | 25 .833333 |
| PSHELL   | 40        | 25     | .003                             | 25      | 1.0             | 25 .833333 |
| PARAM  | COUPMASS1 |        |                                  |         |                 |            |
| PARAM  | GRDPNT 0  |        |                                  |         |                 |            |
| PARAM  | USETPRT 1 |        |                                  |         |                 |            |
| SPC1   | 102       |        |                                  |         |                 |            |
| ENDDATA  |           |        |                                  |         |                 |            |

## **Appendix A, cont.**

### **NASTRAN Selected Static Output**

MESSAGES FROM THE PLOT MODULE

PLOTTER DATA

THE FOLLOWING PLOTS ARE FOR A NASTPLT PLOTTER

PAPER SIZE = 20.0 X 20.0, PAPER TYPE = VELLUM

PEN 1 - SIZE 1, BLACK  
PEN 2 - SIZE 1, BLACK  
PEN 3 - SIZE 1, BLACK  
PEN 4 - SIZE 1, BLACK

ENGINEERING DATA

ORTHOGRAPHIC PROJECTION  
ROTATIONS (DEGREES) - GAMMA = 0.00, BETA = 0.00, ALPHA = 0.00, AXES = -Y,+X,+Z, SYMMETRIC  
SCALE (OBJECT-TO-PLOT SIZE) = 2.947904E+01

ORIGIN 1 - X0 = -9.280000E+00, Y0 = -9.600000E-01 (INCHES)

LIST OF PLOTS

PLOT 1 UNDEFORMED SHAPE  
1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 15  
SIDE VIEW PANEL STRESSES (MOD14)

0 OUTPUT FROM GRID POINT WEIGHT GENERATOR  
0 REFERENCE POINT = 0  
M O  
\* 1.655534E+01 5.522655E-19 3.388132E-21 -2.562657E-19 5.095386E+00 2.510267E-17 \*  
\* 5.217723E-19 1.655534E+01 0.000000E+00 -5.095386E+00 1.641892E-19 3.851628E-17 \*  
\* 4.065758E-20 0.000000E+00 1.655534E+01 -1.660862E-17 -4.176889E-17 -1.090491E-19 \*  
\* -2.517196E-19 -5.095386E+00 -2.043721E-17 2.685863E+00 9.622294E-19 9.741726E-18 \*  
\* 5.095386E+00 1.643208E-19 1.626303E-18 -1.136718E-18 2.685863E+00 7.051549E-19 \*  
\* 1.940722E-17 7.264155E-18 -1.111361E-19 -1.632910E-17 7.002421E-18 1.028373E+00 \*

S  
\* 1.000000E+00 0.000000E+00 0.000000E+00 \*  
\* 0.000000E+00 1.000000E+00 0.000000E+00 \*  
\* 0.000000E+00 0.000000E+00 1.000000E+00 \*  
DIRECTION  
MASS AXIS SYSTEM (S) MASS X-C.G. Y-C.G. Z-C.G.  
X 1.655534E+01 -1.547934E-20 -1.516289E-18 3.077791E-01  
Y 1.655534E+01 2.326518E-18 9.917600E-21 3.077791E-01  
Z 1.655534E+01 2.522986E-18 -1.003219E-18 -6.586943E-21  
I(S)  
\* 1.117610E+00 -9.622294E-19 -2.159623E-17 \*  
\* -9.622294E-19 1.117610E+00 7.020921E-18 \*  
\* -2.159623E-17 7.020921E-18 1.028373E+00 \*  
I(Q)  
\* 1.117610E+00 \*  
\* 1.117610E+00 \*  
\* 1.028373E+00 \*  
Q  
\* 1.000000E+00 0.000000E+00 0.000000E+00 \*  
\* 0.000000E+00 1.000000E+00 0.000000E+00 \*  
\* 0.000000E+00 0.000000E+00 1.000000E+00 \*

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 16  
SIDE VIEW PANEL STRESSES (MOD14)

0  
1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 17  
SIDE VIEW PANEL STRESSES (MOD14)

0  
0 OLOAD RESULTANT  
0 T1 T2 T3 R1 R2 R3  
0 1 5.678480E+02 1.8697655E-17 -1.7864865E+03 0.0000000E+00 1.7477174E+02 0.0000000E+00  
1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 18  
SIDE VIEW PANEL STRESSES (MOD14)

USET DEFINITION TABLE (INTERNAL SEQUENCE, COLUMN SORT)

| INT | DOP | INT GP. | EXT GP. | DOP | SB | SG | L  | A  | F  | N  | G  | R | O | S | M | E | INT DOP |
|-----|-----|---------|---------|-----|----|----|----|----|----|----|----|---|---|---|---|---|---------|
| 1-  |     | 1 G     | 8       | - 1 |    |    | 1  | 1  | 1  | 1  | 1  |   |   |   |   | - | 1       |
| 2-  |     |         |         | - 2 |    |    | 2  | 2  | 2  | 2  | 2  |   |   |   |   | - | 2       |
| 3-  |     |         |         | - 3 |    |    | 3  | 3  | 3  | 3  | 3  |   |   |   |   | - | 3       |
| 4-  |     |         |         | - 4 |    |    | 4  | 4  | 4  | 4  | 4  |   |   |   |   | - | 4       |
| 5-  |     |         |         | - 5 |    |    | 5  | 5  | 5  | 5  | 5  |   |   |   |   | - | 5       |
| 6-  |     |         |         | - 6 |    |    | 6  | 6  | 6  | 6  | 6  |   |   |   |   | - | 6       |
| 7-  |     | 2 G     | 9       | - 1 |    |    | 7  | 7  | 7  | 7  | 7  |   |   |   |   | - | 7       |
| 8-  |     |         |         | - 2 |    |    | 8  | 8  | 8  | 8  | 8  |   |   |   |   | - | 8       |
| 9-  |     |         |         | - 3 |    |    | 9  | 9  | 9  | 9  | 9  |   |   |   |   | - | 9       |
| 10- |     |         |         | - 4 |    |    | 10 | 10 | 10 | 10 | 10 |   |   |   |   | - | 10      |
| 11- |     |         |         | - 5 |    |    | 11 | 11 | 11 | 11 | 11 |   |   |   |   | - | 11      |
| 12- |     |         |         | - 6 |    |    | 12 | 12 | 12 | 12 | 12 |   |   |   |   | - | 12      |
| 13- |     | 3 G     | 7       | - 1 |    |    | 13 | 13 | 13 | 13 | 13 |   |   |   |   | - | 13      |
| 14- |     |         |         | - 2 |    |    | 14 | 14 | 14 | 14 | 14 |   |   |   |   | - | 14      |
| 15- |     |         |         | - 3 |    |    | 15 | 15 | 15 | 15 | 15 |   |   |   |   | - | 15      |
| 16- |     |         |         | - 4 |    |    | 16 | 16 | 16 | 16 | 16 |   |   |   |   | - | 16      |
| 17- |     |         |         | - 5 |    |    | 17 | 17 | 17 | 17 | 17 |   |   |   |   | - | 17      |
| 18- |     |         |         | - 6 |    |    | 18 | 18 | 18 | 18 | 18 |   |   |   |   | - | 18      |

| ELEMENT ID. | FORCES IN BAR ELEMENTS (C BAR) |               |                   |               |               |               |               |               |         |         | AXIAL FORCE | TORQUE |
|-------------|--------------------------------|---------------|-------------------|---------------|---------------|---------------|---------------|---------------|---------|---------|-------------|--------|
|             | BEND-MOMENT END-A              |               | BEND-MOMENT END-B |               | - SHEAR -     |               | PLANE 1       |               | PLANE 2 |         |             |        |
|             | PLANE 1                        | PLANE 2       | PLANE 1           | PLANE 2       | PLANE 1       | PLANE 2       | PLANE 1       | PLANE 2       | PLANE 1 | PLANE 2 |             |        |
| 1           | -3.590761E-13                  | 2.144488E-02  | 1.106471E-13      | -3.499864E-02 | -5.565014E-12 | 6.687108E-01  | 1.084783E+01  | 2.971920E-13  |         |         |             |        |
| 2           | 9.351339E-14                   | -7.868370E-02 | -5.512026E-14     | 6.357207E-02  | 1.762736E-12  | -1.687097E+00 | -4.457223E+01 | 2.931055E-14  |         |         |             |        |
| 3           | 1.595531E-15                   | 1.171102E-02  | 6.130488E-17      | 4.705452E-03  | 9.097656E-15  | 4.154160E-02  | -2.166726E+01 | 4.877645E-15  |         |         |             |        |
| 4           | -1.228829E-15                  | -1.854249E-02 | 1.752490E-15      | 1.526943E-02  | -1.767231E-14 | -2.004263E-01 | -9.374801E+00 | 5.545486E-15  |         |         |             |        |
| 5           | 1.426244E-14                   | -9.070121E-03 | -2.129563E-14     | 6.221632E-03  | 2.107441E-13  | -9.063052E-02 | -4.976630E+00 | 1.440544E-14  |         |         |             |        |
| 6           | -6.618376E-14                  | -1.165417E-03 | 1.811587E-13      | -6.451873E-04 | -1.465939E-12 | -3.083276E-03 | -3.507457E+00 | 1.006417E-13  |         |         |             |        |
| 7           | 1.328638E-13                   | -2.028330E-02 | -3.653876E-14     | 3.386560E-02  | 6.557756E-13  | -2.096162E-01 | 4.985665E-01  | 4.359654E-14  |         |         |             |        |
| 8           | -2.132455E-15                  | -2.535553E-02 | 1.344051E-15      | 2.400393E-02  | -1.337118E-14 | -1.898441E-01 | -1.100659E+00 | 4.275405E-14  |         |         |             |        |
| 9           | 4.161772E-14                   | -4.294580E-02 | -1.513211E-13     | 3.454868E-02  | 7.468870E-13  | -2.999895E-01 | -4.480549E+01 | 7.227024E-14  |         |         |             |        |
| 10          | -5.952623E-15                  | 9.743042E-03  | -5.127953E-14     | -4.993476E-02 | 6.691468E-13  | 8.810045E-01  | -1.761725E+00 | 1.418675E-14  |         |         |             |        |
| 11          | 1.322520E-14                   | 3.175361E-02  | 6.467260E-14      | -5.863283E-02 | -7.602582E-13 | 1.335675E+00  | -4.260091E+01 | 4.193039E-14  |         |         |             |        |
| 12          | 3.634989E-13                   | 2.221957E-03  | -1.072898E-13     | -8.128450E-03 | 5.577639E-12  | 1.226258E-01  | 6.335533E+00  | 2.048117E-13  |         |         |             |        |
| 13          | -1.081138E-13                  | -2.412591E-02 | 6.346715E-14      | 1.481274E-02  | -2.034882E-12 | -4.617968E-01 | 9.981408E-01  | 3.063550E-14  |         |         |             |        |
| 14          | -1.728371E-15                  | 6.843613E-03  | 1.359432E-16      | -1.015999E-02 | -1.105501E-14 | 1.008280E-01  | -4.439110E+00 | 5.438592E-15  |         |         |             |        |
| 15          | 7.309290E-16                   | 1.425886E-02  | -8.789696E-16     | -1.503234E-02 | 9.542967E-15  | 1.736289E-01  | -3.945104E+00 | 6.197978E-15  |         |         |             |        |
| 16          | -1.308880E-14                  | 1.208695E-02  | 1.856686E-14      | -7.169246E-03 | -1.876154E-13 | 1.141268E-01  | -2.755921E+00 | 1.234841E-14  |         |         |             |        |
| 17          | 7.212072E-14                   | -8.711179E-04 | -1.935405E-13     | 3.412962E-03  | 1.574510E-12  | -2.539071E-02 | -2.956770E+00 | 1.633147E-13  |         |         |             |        |
| 18          | -1.544750E-13                  | 2.639141E-02  | 3.941676E-14      | -4.402583E-02 | -7.505758E-13 | 2.725927E-01  | 3.750731E+00  | 7.348701E-14  |         |         |             |        |
| 19          | -1.642413E-17                  | 3.349094E-02  | -2.877231E-15     | -3.546562E-02 | 1.100310E-14  | 2.652175E-01  | -1.362224E+00 | 4.491782E-14  |         |         |             |        |
| 20          | -4.162522E-14                  | 4.714065E-02  | 1.422348E-13      | -2.475102E-02 | -7.117421E-13 | 2.783004E-01  | -1.513659E+01 | 4.933161E-14  |         |         |             |        |
| 21          | 1.037460E-14                   | -4.232702E-02 | 6.196352E-14      | 9.099621E-02  | -7.615908E-13 | -1.968208E+00 | 3.329189E+00  | 4.081806E-14  |         |         |             |        |
| 22          | -9.311121E-15                  | -3.312795E-02 | -5.821990E-14     | 9.136084E-02  | 7.227440E-13  | -1.839619E+00 | -1.124533E+01 | 1.930331E-14  |         |         |             |        |
| 23          | -7.486548E-13                  | 2.777270E-02  | 8.036280E-13      | -2.901038E-02 | -1.841379E-11 | 6.735834E-01  | 2.196456E+00  | -7.129661E-14 |         |         |             |        |
| 24          | -8.993340E-13                  | -3.153107E-02 | 8.033114E-13      | 2.961048E-02  | -2.019745E-11 | -7.252854E-01 | 2.873801E+00  | -6.588983E-13 |         |         |             |        |
| 25          | -5.234889E-13                  | 2.958771E-02  | 4.291914E-13      | -2.834926E-02 | -1.130107E-11 | 6.872713E-01  | -2.271778E+00 | 2.509357E-14  |         |         |             |        |
| 26          | -3.726431E-13                  | -3.133868E-02 | 4.259350E-13      | 2.865491E-02  | -9.473051E-12 | -7.116678E-01 | -1.734441E+00 | -7.542984E-13 |         |         |             |        |
| 27          | 1.216083E-02                   | 1.574923E-02  | -2.040341E-02     | -2.481064E-02 | 3.859239E-01  | 4.806812E-01  | 1.055563E+01  | 7.077573E-04  |         |         |             |        |
| 28          | -3.754690E-02                  | -6.229705E-02 | 3.001979E-02      | 5.104756E-02  | -8.007433E-01 | -1.343264E+00 | -4.148076E+01 | -5.417068E-03 |         |         |             |        |
| 29          | 9.989605E-03                   | 3.814772E-03  | 2.994690E-03      | 4.665184E-03  | 4.148832E-02  | -5.043976E-03 | -2.052173E+01 | -2.990394E-04 |         |         |             |        |
| 30          | -1.550547E-02                  | -9.609520E-03 | 1.294831E-02      | 8.068538E-03  | -1.686650E-01 | -1.047899E-01 | -9.010637E+00 | -3.567546E-05 |         |         |             |        |
| 31          | -7.973676E-03                  | -4.767393E-03 | 5.381461E-03      | 3.263598E-03  | -7.917146E-02 | -4.760905E-02 | -4.826252E+00 | 2.786209E-04  |         |         |             |        |
| 32          | -8.113426E-04                  | -6.572965E-04 | -6.898224E-04     | -5.011598E-04 | -7.200772E-04 | -9.252005E-04 | -3.471506E+00 | 1.017989E-04  |         |         |             |        |
| 33          | 2.009037E-02                   | -8.003619E-03 | -3.339788E-02     | 1.354119E-02  | 2.070886E-01  | -8.341134E-02 | 7.196137E-01  | -2.162914E-03 |         |         |             |        |
| 34          | 2.302230E-02                   | -1.185355E-02 | -2.066055E-02     | 1.369357E-02  | 1.680110E-01  | -9.825817E-02 | -1.122436E+00 | -3.731592E-04 |         |         |             |        |
| 35          | 2.654099E-02                   | -3.586927E-02 | -2.085124E-02     | 2.808128E-02  | 1.834804E-01  | -2.475864E-01 | -4.283487E+01 | -3.329445E-03 |         |         |             |        |
| 36          | -1.493154E-02                  | 7.809504E-04  | 5.515825E-02      | -1.63347E-02  | -1.034726E+00 | 2.526578E-01  | -1.414710E+00 | -6.275317E-03 |         |         |             |        |
| 37          | 1.788837E-02                   | 2.797319E-02  | -3.137875E-02     | -5.672431E-02 | 7.280481E-01  | 1.251623E+00  | -4.051399E+00 | 5.876750E-03  |         |         |             |        |
| 38          | -4.189087E-04                  | 1.205415E-03  | -2.824195E-03     | -4.489919E-03 | 2.850542E-02  | 6.749628E-02  | 6.643507E+00  | -6.995315E-04 |         |         |             |        |
| 39          | -1.930806E-03                  | -2.111342E-02 | -1.813357E-03     | 1.420500E-02  | -1.391904E-03 | -4.185641E-01 | -2.095360E+00 | 5.384411E-03  |         |         |             |        |
| 40          | 5.976103E-03                   | 1.138874E-03  | -9.383663E-03     | -3.587015E-03 | 9.110200E-02  | 2.803025E-02  | -5.594239E+00 | 3.135261E-04  |         |         |             |        |
| 41          | 1.288231E-02                   | 6.772039E-03  | -1.328888E-02     | -7.072475E-03 | 1.551345E-01  | 8.206587E-02  | -4.310146E+00 | 4.140049E-05  |         |         |             |        |
| 42          | 9.643014E-03                   | 6.968013E-03  | -5.767337E-03     | -4.167014E-03 | 9.135512E-02  | 6.601029E-02  | -2.903188E+00 | -2.746614E-04 |         |         |             |        |
| 43          | -6.202278E-04                  | -4.336690E-04 | 1.966204E-03      | 2.565781E-03  | -1.532610E-02 | -1.777347E-02 | -2.990755E+00 | -1.026632E-04 |         |         |             |        |
| 44          | -1.619169E-02                  | 2.128040E-02  | 2.715116E-02      | -3.533000E-02 | -1.678031E-01 | 2.191688E-01  | 3.353139E+00  | -2.160661E-03 |         |         |             |        |
| 45          | -2.788747E-02                  | 1.754001E-02  | 3.077885E-02      | -1.603634E-02 | -2.256397E-01 | 1.291398E-01  | -1.346140E+00 | 4.118293E-04  |         |         |             |        |
| 46          | -4.341981E-02                  | 2.077136E-02  | 2.520260E-02      | -9.200518E-03 | -2.656736E-01 | 1.160370E-01  | -1.714005E+01 | 3.317879E-03  |         |         |             |        |
| 47          | 2.453551E-02                   | -3.301664E-02 | -5.172138E-02     | 7.516263E-02  | 1.125770E+00  | -1.597035E+00 | 2.991270E+00  | 6.250551E-03  |         |         |             |        |
| 48          | -3.119554E-02                  | -1.430750E-02 | 8.216929E-02      | 4.102083E-02  | -1.675256E+00 | -8.176181E-01 | -1.336062E+01 | -5.886101E-03 |         |         |             |        |
| 49          | 4.257632E-04                   | 2.801530E-02  | -3.075795E-04     | -2.903874E-02 | 8.697152E-03  | 6.766381E-01  | 2.239632E+00  | 1.665154E-04  |         |         |             |        |
| 50          | 4.222245E-04                   | 3.126584E-02  | -3.058539E-04     | 2.955695E-02  | 8.634720E-03  | -7.213342E-01 | 2.826720E+00  | -1.673221E-04 |         |         |             |        |

| 0  | ELEMENT ID.   | FORCES IN BAR ELEMENTS (C BAR) |               |                   |               |               |               |               |         |         |         | AXIAL FORCE | TORQUE |
|----|---------------|--------------------------------|---------------|-------------------|---------------|---------------|---------------|---------------|---------|---------|---------|-------------|--------|
|    |               | BEND-MOMENT END-A              |               | BEND-MOMENT END-B |               | - SHEAR -     |               | PLANE 1       |         | PLANE 2 |         |             |        |
|    |               | PLANE 1                        | PLANE 2       | PLANE 1           | PLANE 2       | PLANE 1       | PLANE 2       | PLANE 1       | PLANE 2 | PLANE 1 | PLANE 2 |             |        |
| 51 | 4.815668E-04  | 2.969050E-02                   | -2.992716E-04 | -2.835599E-02     | 9.260433E-03  | 6.884083E-01  | -2.236255E+00 | 1.300307E-04  |         |         |         |             |        |
| 52 | 4.816061E-04  | -3.120659E-02                  | -2.992316E-04 | 2.862079E-02      | 9.260423E-03  | -7.095288E-01 | -1.770165E+00 | -1.320234E-04 |         |         |         |             |        |
| 53 | 1.161587E-02  | -1.049281E-02                  | -1.690304E-02 | 1.740152E-02      | 3.379820E-01  | -3.305800E-01 | 9.734171E+00  | 1.198611E-03  |         |         |         |             |        |
| 54 | -5.079036E-02 | 2.598196E-02                   | 4.270640E-02  | -2.112120E-02     | -1.108044E+00 | 5.582267E-01  | -3.318760E+01 | -9.317691E-03 |         |         |         |             |        |
| 55 | 3.582076E-03  | -7.319125E-03                  | 7.187615E-03  | -1.720148E-04     | -2.138521E-02 | -4.239102E-02 | -1.735949E+01 | -5.475537E-04 |         |         |         |             |        |
| 56 | -1.561429E-02 | 7.863455E-03                   | 1.361659E-02  | -6.824913E-03     | -1.732713E-01 | 8.706798E-02  | -8.017959E+00 | -7.531007E-05 |         |         |         |             |        |
| 57 | -7.746551E-03 | 6.101894E-03                   | 5.117561E-03  | -3.973575E-03     | -7.626059E-02 | 5.972905E-02  | -4.420108E+00 | 4.723465E-04  |         |         |         |             |        |
| 58 | -1.841763E-04 | 7.080293E-04                   | -6.230299E-04 | 1.228768E-03      | 2.600461E-03  | -3.085678E-03 | -3.367541E+00 | 1.784743E-04  |         |         |         |             |        |
| 59 | 9.994888E-03  | 2.228367E-02                   | -1.693849E-02 | 3.689345E-02      | 1.042912E-01  | 2.291059E-01  | 1.305749E+00  | 3.738959E-03  |         |         |         |             |        |
| 60 | 2.260979E-02  | 1.554239E-02                   | -2.453909E-02 | -1.116628E-02     | 1.813418E-01  | 1.027256E-01  | -1.171019E+00 | -7.149538E-04 |         |         |         |             |        |
| 61 | 4.626993E-02  | 1.264653E-02                   | -3.437777E-02 | -8.465639E-03     | 3.122299E-01  | 8.173636E-02  | -3.742892E+01 | -5.748353E-03 |         |         |         |             |        |
| 62 | -3.257121E-03 | -2.359012E-02                  | 1.919570E-02  | 6.991457E-02      | -3.314678E-01 | -1.380397E+00 | -4.915852E-01 | -1.082779E-02 |         |         |         |             |        |
| 63 | 3.493507E-02  | -8.456687E-03                  | -7.577238E-02 | 1.408836E-02      | 1.635987E+00  | -3.331609E-01 | -3.479886E+01 | 1.019692E-02  |         |         |         |             |        |
| 64 | -9.638674E-04 | 4.051004E-03                   | 6.761833E-04  | -2.919202E-03     | -1.943649E-02 | 8.260497E-02  | 7.464971E+00  | -1.206837E-03 |         |         |         |             |        |
| 65 | -1.517426E-02 | -1.520166E-02                  | 1.087325E-02  | 1.572136E-02      | -3.086930E-01 | -3.664735E-01 | -1.038853E+01 | 9.350347E-03  |         |         |         |             |        |
| 66 | -4.314262E-04 | -4.643227E-03                  | -5.190738E-03 | 8.080184E-03      | 2.822848E-02  | -7.546524E-02 | -8.756479E+00 | 5.330670E-04  |         |         |         |             |        |
| 67 | 1.277350E-02  | -8.518103E-03                  | -1.262059E-02 | 8.316101E-03      | 1.505281E-01  | -9.978780E-02 | -5.302825E+00 | 6.958505E-05  |         |         |         |             |        |
| 68 | 9.870138E-03  | -5.633512E-03                  | -6.031237E-03 | 3.457037E-03      | 9.426299E-01  | -5.389028E-02 | -3.309331E+00 | -4.763060E-04 |         |         |         |             |        |
| 69 | 6.938424E-06  | 4.844018E-04                   | 2.032996E-03  | -1.838717E-03     | -1.200556E-02 | 1.376259E-02  | -3.094721E+00 | -1.776100E-04 |         |         |         |             |        |
| 70 | -2.828257E-02 | -7.000344E-03                  | 4.361244E-02  | 1.197774E-02      | -2.706006E-01 | -7.347420E-02 | 2.949004E+00  | -3.741247E-03 |         |         |         |             |        |
| 71 | -2.829999E-02 | -1.385117E-02                  | 2.690031E-02  | 1.856363E-02      | -2.123088E-01 | -1.246723E-01 | -2.197558E+00 | 6.76283E-04   |         |         |         |             |        |
| 72 | -2.369807E-02 | -4.399411E-02                  | 1.167607E-02  | 2.881615E-02      | -1.369241E-01 | -2.818870E-01 | -2.125459E+01 | 5.759919E-03  |         |         |         |             |        |
| 73 | 3.620993E-02  | 1.020747E-02                   | -8.768392E-02 | -2.158153E-02     | 1.829027E+00  | 4.692965E-01  | 2.068146E+00  | 1.085255E-02  |         |         |         |             |        |
| 74 | -1.414884E-03 | 3.382400E-03                   | 3.777566E-02  | -8.365679E-02     | -7.673178E-01 | 1.736080E+00  | -1.907575E+01 | -1.018775E-02 |         |         |         |             |        |
| 75 | -7.307676E-04 | -2.870341E-02                  | 5.292339E-04  | 2.914898E-02      | -1.494132E-02 | -6.861063E-01 | 2.363853E+00  | 2.876661E-04  |         |         |         |             |        |
| 76 | -7.343062E-04 | 3.057773E-03                   | 5.309596E-04  | -2.944672E-02     | -1.500555E-02 | 7.118660E-01  | 2.702499E+00  | -2.867593E-04 |         |         |         |             |        |
| 77 | -8.742427E-04 | -3.001085E-02                  | 5.198264E-04  | 2.841203E-02      | -1.609546E-02 | -6.928721E-01 | -2.138038E+00 | 2.271382E-04  |         |         |         |             |        |
| 78 | -8.373854E-04 | 3.088623E-02                   | 5.198665E-04  | -2.856475E-02     | -1.609647E-02 | 7.050650E-01  | -1.868382E+00 | -2.251455E-04 |         |         |         |             |        |
| 79 | 2.218983E-03  | -9.611459E-03                  | -1.614133E-03 | 1.343509E-02      | 4.541259E-02  | -2.730425E-01 | 8.591681E+00  | 1.393502E-03  |         |         |         |             |        |
| 80 | -2.475919E-02 | 2.727889E-02                   | 2.138408E-02  | -2.37967E-02      | -5.472408E-01 | 6.126499E-01  | -2.178704E+01 | -1.079295E-02 |         |         |         |             |        |
| 81 | -4.736858E-03 | -2.433702E-03                  | 4.441009E-03  | -7.432719E-03     | -5.442293E-02 | 2.964318E-02  | -1.305319E+01 | -6.213687E-02 |         |         |         |             |        |
| 82 | -1.147575E-03 | 1.640067E-02                   | 1.033259E-03  | -1.515089E-03     | -1.292729E-02 | 1.870276E-01  | -6.659952E+00 | -8.151900E-05 |         |         |         |             |        |
| 83 | 3.661488E-04  | 1.057854E-02                   | -5.384588E-04 | -6.695439E-03     | 8.561840E-03  | 1.023787E-01  | -3.866276E+00 | 5.530859E-04  |         |         |         |             |        |
| 84 | 1.666877E-04  | 1.471495E-04                   | 8.86380E-04   | 2.029705E-03      | -1.300967E-04 | -1.152371E-02 | -3.232114E+00 | 2.042179E-04  |         |         |         |             |        |
| 85 | -1.277510E-02 | 2.333735E-02                   | 2.087355E-02  | -3.894572E-02     | -1.302576E-01 | 2.11045E-01   | 2.126469E+00  | 4.319953E-03  |         |         |         |             |        |
| 86 | -2.490008E-03 | 2.942323E-02                   | -3.021410E-03 | -2.973478E-02     | 2.043857E-02  | 2.275308E-01  | -1.231441E+00 | -7.983861E-04 |         |         |         |             |        |
| 87 | 2.229456E-02  | 4.504322E-02                   | -1.738811E-02 | -2.964985E-02     | 1.536159E-01  | 2.891449E-01  | -2.997104E+01 | -6.645053E-03 |         |         |         |             |        |
| 88 | 1.824134E-02  | -2.603503E-02                  | 4.692085E-02  | 7.046549E-02      | 9.619878E-01  | -1.424606E+00 | 7.837318E-01  | -1.252023E-02 |         |         |         |             |        |
| 89 | 1.895599E-02  | -3.244078E-02                  | -4.482878E-02 | 7.499683E-02      | 4.527524E-01  | -1.587647E+00 | -2.692312E+01 | 1.176799E-02  |         |         |         |             |        |

|     |               |               |               |               |               |               |               |               |
|-----|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| 266 | 5.840750E+02  | -2.340509E+03 | -2.622489E+03 | -4.725084E-02 | -6.591293E-02 | 4.349691E-02  | -7.667595E+00 | -1.758206E+01 |
| 267 | 1.145086E+03  | -7.123824E+02 | -7.507527E+02 | 3.790018E-02  | 1.053804E-01  | 5.426811E-03  | 4.208248E-01  | -2.385860E-01 |
| 268 | 3.440515E+02  | -4.324756E+02 | -2.731831E+02 | -3.679375E-03 | -1.526136E-02 | 8.543625E-05  | -6.687283E-01 | -3.425724E+00 |
| 269 | 9.214516E+01  | -2.944826E+02 | -1.239226E+02 | -1.827132E-02 | -3.533856E-02 | -6.650033E-04 | -9.339312E-01 | -1.847940E+00 |
| 270 | -5.784969E+01 | -2.901468E+02 | -7.358328E+01 | -7.397202E-03 | -1.956263E-02 | -1.072379E-03 | -4.089126E-01 | 1.513366E-01  |
| 271 | 3.014476E+02  | 7.384348E+02  | -1.235699E+02 | -1.069292E-02 | -1.516873E-02 | -6.864618E-03 | -6.372569E+00 | 3.452614E+00  |
| 272 | 4.704423E+02  | -1.362935E+03 | 2.625096E+03  | -9.306367E-03 | 3.171459E-04  | -4.362293E-02 | 7.674496E+00  | -6.718120E+00 |
| 273 | 8.230325E+02  | -5.186360E+02 | 7.503003E+02  | 2.915794E-02  | 7.622188E-02  | -5.410534E-03 | -4.284848E-01 | -8.672036E-01 |
| 274 | 2.550189E+02  | -3.608545E+02 | 2.731595E+02  | -3.661976E-03 | -7.138585E-03 | -5.767200E-05 | 6.704285E-01  | -3.297414E+00 |
| 275 | 3.022311E+01  | -2.688803E+02 | 1.238849E+02  | -2.260741E-02 | -4.097283E-02 | 6.670963E-04  | 9.365753E-01  | -1.961423E+00 |
| 276 | -9.339983E+01 | -2.887101E+02 | 7.364703E+01  | -7.707814E-03 | -2.123360E-02 | 1.069567E-03  | 4.093098E-01  | 2.930611E-01  |
| 277 | 3.014476E+02  | 7.384348E+02  | 1.235699E+02  | -1.069292E-02 | -1.516873E-02 | 6.864618E-03  | 6.372569E+00  | 3.452614E+00  |
| 278 | 4.704423E+02  | -1.362935E+03 | 2.625096E+03  | -9.306367E-03 | 3.171459E-04  | -4.362293E-02 | -7.674496E+00 | -6.718120E+00 |
| 279 | 8.230325E+02  | -5.186360E+02 | 7.503003E+02  | 2.915794E-02  | 7.622188E-02  | -5.410534E-03 | 4.284848E-01  | -8.672036E-01 |
| 280 | 2.550189E+02  | -3.608545E+02 | 2.731595E+02  | -3.661976E-03 | -7.138585E-03 | -5.767200E-05 | -6.704285E-01 | -3.297414E+00 |
| 281 | 3.022311E+01  | -2.688803E+02 | 1.238849E+02  | -2.260741E-02 | -4.097283E-02 | 6.670963E-04  | -9.365753E-01 | -1.961423E+00 |
| 282 | -9.339983E+01 | -2.887101E+02 | 7.364703E+01  | -7.707814E-03 | -2.123360E-02 | 1.069567E-03  | -4.093098E-01 | 2.930611E-01  |
| 283 | 3.534035E+02  | 8.471934E+02  | -1.234523E+02 | -3.777957E-02 | -6.372009E-02 | -6.865422E-03 | -6.361629E+00 | 7.393185E+00  |
| 284 | 5.840750E+02  | -2.340509E+03 | 2.622489E+03  | -4.725084E-02 | -6.591293E-02 | 4.349691E-02  | 7.667595E+00  | -1.758206E+01 |
| 285 | 1.145086E+03  | -7.123824E+02 | 7.507527E+02  | 3.790018E-02  | 1.053804E-01  | 5.426811E-03  | -4.208248E-01 | -2.385860E-01 |
| 286 | 3.440515E+02  | -4.324756E+02 | 2.731831E+02  | -3.679375E-03 | -1.526136E-02 | 8.543625E-05  | 6.687283E-01  | -3.425724E+00 |
| 287 | 9.214516E+01  | -2.944826E+02 | 1.239226E+02  | -1.827132E-02 | -3.533856E-02 | -6.650033E-04 | 9.339312E-01  | -1.847940E+00 |
| 288 | -5.784969E+01 | -2.901468E+02 | 7.358328E+01  | -7.397202E-03 | -1.956263E-02 | -1.072379E-03 | -4.089126E-01 | 1.513366E-01  |
| 289 | 2.555121E+02  | 6.450062E+02  | 9.034018E+01  | 1.278056E-02  | 2.691199E-02  | 5.030826E-03  | 4.682122E+00  | 3.221761E-02  |
| 290 | 3.725855E+02  | -5.191925E+02 | -1.919869E+03 | 2.362441E-02  | 5.660649E-02  | 3.189762E-02  | -5.636991E+00 | 2.673728E+00  |

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 47  
SIDE VIEW PANEL STRESSES (MOD14) SUBCASE 1

# FORCES IN QUADRILATERAL ELEMENTS (QUAD4)

| ELEMENT ID | - MEMBRANE FORCES - |               |               | - BENDING MOMENTS - |               |               | - TRANSVERSE SHEAR FORCES - |               |
|------------|---------------------|---------------|---------------|---------------------|---------------|---------------|-----------------------------|---------------|
|            | FX                  | FY            | FX            | MY                  | MY            | MY            | QX                          | QY            |
| 291        | 5.440270E+02        | -3.508220E+02 | -5.494080E+02 | 2.155004E-02        | 5.090450E-02  | 3.964988E-03  | 3.080928E-01                | -1.413865E+00 |
| 292        | 1.779070E+02        | -2.988895E+02 | -1.999196E+02 | -3.601516E-03       | -6.561957E-05 | 4.963365E-05  | -4.906484E-01               | -3.185804E+00 |
| 293        | -2.333251E-01       | -2.465347E+02 | -9.074060E+01 | -2.639591E-02       | -4.586403E-02 | -4.875443E-04 | -6.834825E-01               | -2.061070E+00 |
| 294        | -1.241116E+02       | -2.873113E+02 | -5.388642E+01 | -8.053681E-03       | -2.270973E-02 | -7.830276E-04 | -3.029959E-01               | 4.160261E-01  |
| 295        | 3.984750E+02        | 9.417280E+02  | -9.034018E+01 | -6.117753E-02       | -1.057644E-01 | -5.030826E-03 | -4.682122E+00               | 1.082029E+01  |
| 296        | 6.808348E+02        | -3.188227E+03 | 1.919869E+03  | -8.031138E-02       | -1.226618E-01 | -3.189762E-02 | 5.636991E+00                | -2.695327E+01 |
| 297        | 1.424169E+03        | -8.805180E+02 | 5.494080E+02  | 4.504438E-02        | 1.303880E-01  | -3.964988E-03 | -3.080928E-01               | 3.051223E-01  |
| 298        | 4.212050E+02        | -4.944595E+02 | 1.999196E+02  | -3.886455E-03       | -2.231827E-02 | 4.963365E-05  | 4.906484E-01                | -3.535986E+00 |
| 299        | 1.456992E+02        | -3.165609E+02 | 9.074060E+01  | -1.453263E-02       | -3.048427E-02 | 4.875443E-04  | 6.834825E-01                | -1.749176E+00 |
| 300        | -2.685900E+01       | -2.916120E+02 | 5.388642E+01  | -7.097768E-02       | -1.809774E-02 | 7.830276E-04  | 3.029959E-01                | 2.856101E-02  |
| 301        | 2.305433E+02        | 5.906006E+02  | 3.302573E+01  | 2.629867E-02        | 5.117396E-02  | 1.830485E-03  | 1.705994E+00                | -1.940346E+00 |
| 302        | 3.164997E+02        | -3.004304E+01 | -7.029039E+02 | 4.270343E-02        | 8.946729E-02  | 1.166887E-02  | -2.052203E+00               | 8.095702E+00  |
| 303        | 3.829587E+02        | -2.535450E+02 | -2.012976E+02 | 1.730427E-02        | 3.636815E-02  | 1.457379E-03  | 1.138642E-01                | -1.728503E+00 |
| 304        | 1.333423E+02        | -2.630892E+02 | -7.316280E+01 | -3.537118E-03       | 4.009573E-03  | 2.040058E-05  | -1.791735E-01               | -3.121838E+00 |
| 305        | -5.424064E+01       | -2.338188E+02 | -3.328263E+01 | -2.855325E-02       | -4.867032E-02 | -1.765705E-04 | -2.498072E-01               | -2.117826E+00 |
| 306        | -1.420886E+02       | -2.864876E+02 | -1.961604E+01 | -8.197386E-02       | -2.354261E-02 | -2.907645E-04 | -1.079436E-01               | 4.868928E-01  |
| 307        | 4.243077E+02        | 9.950275E+02  | -3.14326E+01  | -7.477117E-02       | -1.300628E-01 | -1.829681E-03 | -1.716934E+00               | 1.278614E+01  |
| 308        | 7.380176E+02        | -3.673401E+03 | 7.055115E+02  | -9.926064E-02       | -1.556974E-01 | -1.179488E-02 | 2.059104E+00                | -3.239589E+00 |
| 309        | 1.585160E+03        | -9.774734E+02 | 2.008452E+02  | 4.975385E-02        | 1.452342E-01  | -1.441102E-03 | -1.215242E-01               | 6.227138E-01  |
| 310        | 4.657281E+02        | -5.302409E+02 | 7.313913E+01  | -3.804233E-02       | -2.640952E-02 | 7.363667E-06  | 1.808737E-01                | -3.601300E+00 |
| 311        | 1.766089E+02        | -3.295441E+02 | 3.324495E+01  | -1.232549E-02       | -2.764107E-02 | 1.786635E-04  | 2.524513E-01                | -1.691536E+00 |
| 312        | -9.160946E+00       | -2.923692E+02 | 1.967980E+01  | -6.907630E-03       | -1.725362E-02 | 2.879529E-04  | 1.083408E-01                | -4.249511E-02 |

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 48  
SIDE VIEW PANEL STRESSES (MOD14) SUBCASE 1

# FORCES IN TRIANGULAR ELEMENTS (TRIA3)

| ELEMENT ID | - MEMBRANE FORCES - |               |               | - BENDING MOMENTS - |               |               | - TRANSVERSE SHEAR FORCES - |               |
|------------|---------------------|---------------|---------------|---------------------|---------------|---------------|-----------------------------|---------------|
|            | FX                  | FY            | FX            | MY                  | MY            | MY            | QX                          | QY            |
| 313        | 2.828431E+02        | 3.619044E+02  | -2.006487E+01 | -1.389326E-02       | -1.096154E-02 | 6.959004E-04  | -1.341242E+01               | -3.629241E+00 |
| 314        | 2.797918E+02        | 3.429239E+02  | -1.014448E+01 | -1.033262E-02       | -5.561737E-03 | 2.797052E-03  | -1.349378E+01               | -3.788272E+00 |
| 315        | 2.773234E+02        | 3.074381E+02  | 2.351855E+00  | -2.896355E-03       | 2.433355E-03  | 4.128995E-03  | -1.370117E+01               | -3.955634E+00 |
| 316        | 2.759903E+02        | 2.647839E+02  | 1.404323E+01  | 6.449910E-03        | 1.095433E-02  | 4.385742E-03  | -1.397548E+01               | -3.956221E+00 |
| 317        | 2.758804E+02        | 2.267170E+02  | 2.219034E+01  | 1.522677E-02        | 1.768626E-02  | 3.462604E-03  | -1.419375E+01               | -3.975418E+00 |
| 318        | 2.774180E+02        | 2.033702E+02  | 2.444205E+01  | 2.103826E-02        | 2.075778E-02  | 1.606153E-03  | -1.435229E+01               | -3.954347E+00 |
| 319        | 2.800517E+02        | 2.007365E+02  | 1.988613E+01  | 2.235985E-02        | 1.943618E-02  | -6.800230E-04 | -1.440456E+01               | -3.759483E+00 |
| 320        | 2.828293E+02        | 2.197682E+02  | 1.012404E+01  | 1.883420E-02        | 1.407883E-02  | -2.801517E-03 | -1.428386E+01               | -3.638389E+00 |
| 321        | 2.853529E+02        | 2.554214E+02  | -2.152674E+00 | 1.137873E-02        | 6.025515E-03  | -4.140407E-03 | -1.407927E+01               | -3.569278E+00 |
| 322        | 2.869044E+02        | 2.978571E+02  | -1.422198E+01 | 2.016685E-03        | -2.479685E-03 | -4.369865E-03 | -1.384150E+01               | -3.432503E+00 |
| 323        | 2.867406E+02        | 3.359750E+02  | -2.221077E+01 | -6.725188E-03       | -9.169168E-03 | -3.467069E-03 | -1.358389E+01               | -3.451242E+00 |
| 324        | 2.852584E+02        | 3.594892E+02  | -2.424286E+01 | -1.255589E-02       | -1.229891E-02 | -1.617565E-03 | -1.342816E+01               | -3.570565E+00 |
| 325        | -2.279715E+02       | -1.786455E+02 | -1.196417E+01 | 1.625538E-02        | 1.810005E-02  | 1.587912E-04  | -1.364186E+01               | -3.785041E+00 |
| 326        | -2.285584E+02       | -1.884325E+02 | -5.201788E+00 | 1.780953E-02        | 2.039281E-02  | 1.163792E-03  | -1.361117E+01               | -4.087207E+00 |
| 327        | -2.274201E+02       | -2.071265E+02 | 2.876509E+00  | 2.108722E-02        | 2.367536E-02  | 1.861753E-03  | -1.367714E+01               | -4.315587E+00 |
| 328        | -2.249190E+02       | -2.300799E+02 | 1.015638E+01  | 2.523974E-02        | 2.714378E-02  | 2.045684E-03  | -1.381701E+01               | -4.277997E+00 |
| 329        | -2.218711E+02       | -2.511057E+02 | 1.477013E+01  | 2.913949E-02        | 2.989443E-02  | 1.690253E-03  | -1.394214E+01               | -4.175695E+00 |
| 330        | -2.188461E+02       | -2.640823E+02 | 1.544573E+01  | 3.172157E-02        | 3.106909E-02  | 8.943732E-04  | -1.407550E+01               | -3.976472E+00 |
| 331        | -2.167918E+02       | -2.661366E+02 | 1.189208E+01  | 3.233318E-02        | 3.045748E-02  | -1.636225E-04 | -1.417608E+01               | -3.601804E+00 |
| 332        | -2.163769E+02       | -2.565999E+02 | 5.229742E+00  | 3.078945E-02        | 2.824447E-02  | -1.174821E-03 | -1.416557E+01               | -3.339266E+00 |
| 333        | -2.174104E+02       | -2.375885E+02 | -2.832367E+00 | 2.748939E-02        | 2.489413E-02  | -1.845892E-03 | -1.410312E+01               | -3.211393E+00 |
| 334        | -2.198443E+02       | -2.147022E+02 | -1.022848E+01 | 2.334883E-02        | 2.141375E-02  | -2.050515E-03 | -1.400084E+01               | -3.108848E+00 |
| 335        | -2.230642E+02       | -1.939267E+02 | -1.474218E+01 | 1.945949E-02        | 1.874285E-02  | -1.701282E-03 | -1.383480E+01               | -3.250778E+00 |
| 336        | -2.259844E+02       | -1.806326E+02 | -1.540159E+01 | 1.685503E-02        | 1.750040E-02  | -8.785126E-04 | -1.370477E+01               | -3.550507E+00 |

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 49  
SIDE VIEW PANEL STRESSES (MOD14)

1 BATSAT STRUCTURE MAY 5, 1993 MSC/NASTRAN 9/ 4/91 PAGE 50  
SIDE VIEW PANEL STRESSES (MOD14) SUBCASE 1

| ELEMENT ID |   | STRESSES IN BAR ELEMENTS (CBAR) |            |            |            | SA-MIN           |               | M.S.-T           |  |
|------------|---|---------------------------------|------------|------------|------------|------------------|---------------|------------------|--|
|            |   | SA1<br>SB1                      | SA2<br>SB2 | SA3<br>SB3 | SA4<br>SB4 | SA-MAX<br>SB-MAX | SB-MIN        | M.S.-T<br>M.S.-C |  |
| 0          | 1 | 0.0                             | 0.0        | 0.0        | 0.0        | 2.690234E+05     | 2.690234E+05  | 2.690234E+05     |  |
| 0          | 2 | 0.0                             | 0.0        | 0.0        | 0.0        | -1.105380E+06    | -1.105380E+06 | -1.105380E+06    |  |
| 0          | 3 | 0.0                             | 0.0        | 0.0        | 0.0        | -5.373424E+05    | -5.373424E+05 | -5.373424E+05    |  |

|   |                                  |     |     |     |     |               |                     |               |
|---|----------------------------------|-----|-----|-----|-----|---------------|---------------------|---------------|
| 0 | 4                                | 0.0 | 0.0 | 0.0 | 0.0 | -2.324926E+05 | -5.373424E+05       | -5.373424E+05 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -2.324926E+05 | -2.324926E+05       | -2.324926E+05 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -2.324926E+05 | -2.324926E+05       | -2.324926E+05 |
| 0 | 5                                | 0.0 | 0.0 | 0.0 | 0.0 | -1.234191E+05 | -1.234191E+05       | -1.234191E+05 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -1.234191E+05 | -1.234191E+05       | -1.234191E+05 |
| 0 | 6                                | 0.0 | 0.0 | 0.0 | 0.0 | -8.698404E+04 | -8.698404E+04       | -8.698404E+04 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -8.698404E+04 | -8.698404E+04       | -8.698404E+04 |
| 0 | 7                                | 0.0 | 0.0 | 0.0 | 0.0 | 1.236432E+04  | 1.236432E+04        | 1.236432E+04  |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | 1.236432E+04  | 1.236432E+04        | 1.236432E+04  |
| 0 | 8                                | 0.0 | 0.0 | 0.0 | 0.0 | -2.729605E+04 | -2.729605E+04       | -2.729605E+04 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -2.729605E+04 | -2.729605E+04       | -2.729605E+04 |
| 0 | 9                                | 0.0 | 0.0 | 0.0 | 0.0 | -1.111165E+06 | -1.111165E+06       | -1.111165E+06 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -1.111165E+06 | -1.111165E+06       | -1.111165E+06 |
| 0 | 10                               | 0.0 | 0.0 | 0.0 | 0.0 | -4.369033E+04 | -4.369033E+04       | -4.369033E+04 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -4.369033E+04 | -4.369033E+04       | -4.369033E+04 |
| 0 | 11                               | 0.0 | 0.0 | 0.0 | 0.0 | -1.056492E+06 | -1.056492E+06       | -1.056492E+06 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -1.056492E+06 | -1.056492E+06       | -1.056492E+06 |
| 0 | 12                               | 0.0 | 0.0 | 0.0 | 0.0 | 1.571196E+05  | 1.571196E+05        | 1.571196E+05  |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | 1.571196E+05  | 1.571196E+05        | 1.571196E+05  |
| 0 | 13                               | 0.0 | 0.0 | 0.0 | 0.0 | 2.475363E+04  | 2.475363E+04        | 2.475363E+04  |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | 2.475363E+04  | 2.475363E+04        | 2.475363E+04  |
| 0 | 14                               | 0.0 | 0.0 | 0.0 | 0.0 | -1.100888E+05 | -1.100888E+05       | -1.100888E+05 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -1.100888E+05 | -1.100888E+05       | -1.100888E+05 |
| 0 | 15                               | 0.0 | 0.0 | 0.0 | 0.0 | -9.783756E+04 | -9.783756E+04       | -9.783756E+04 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -9.783756E+04 | -9.783756E+04       | -9.783756E+04 |
| 0 | 16                               | 0.0 | 0.0 | 0.0 | 0.0 | -6.834614E+04 | -6.834614E+04       | -6.834614E+04 |
|   |                                  | 0.0 | 0.0 | 0.0 | 0.0 | -6.834614E+04 | -6.834614E+04       | -6.834614E+04 |
| 1 | BATSAT STRUCTURE                 |     |     |     |     | MAY 5, 1993   | MSC/NASTRAN 9/ 4/91 | PAGE 51       |
|   | SIDE VIEW PANEL STRESSES (MOD14) |     |     |     |     |               |                     |               |

0 SUBCASE 1

| ELEMENT ID. |                                  | SA1 SB1 | SA2 SB2 | SA3 SB3 | SA4 SB4 | AXIAL STRESS  | SA-MAX SB-MAX       | SA-MIN SB-MIN | M.S.-T<br>M.S.-C |
|-------------|----------------------------------|---------|---------|---------|---------|---------------|---------------------|---------------|------------------|
| 0           | 17                               | 0.0     | 0.0     | 0.0     | 0.0     | -7.332713E+04 | -7.332713E+04       | -7.332713E+04 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -7.332713E+04 | -7.332713E+04       | -7.332713E+04 |                  |
| 0           | 18                               | 0.0     | 0.0     | 0.0     | 0.0     | 9.301716E+04  | 9.301716E+04        | 9.301716E+04  |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | 9.301716E+04  | 9.301716E+04        | 9.301716E+04  |                  |
| 0           | 19                               | 0.0     | 0.0     | 0.0     | 0.0     | -3.378280E+04 | -3.378280E+04       | -3.378280E+04 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -3.378280E+04 | -3.378280E+04       | -3.378280E+04 |                  |
| 0           | 20                               | 0.0     | 0.0     | 0.0     | 0.0     | -3.753836E+05 | -3.753836E+05       | -3.753836E+05 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -3.753836E+05 | -3.753836E+05       | -3.753836E+05 |                  |
| 0           | 21                               | 0.0     | 0.0     | 0.0     | 0.0     | 8.256302E+04  | 8.256302E+04        | 8.256302E+04  |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | 8.256302E+04  | 8.256302E+04        | 8.256302E+04  |                  |
| 0           | 22                               | 0.0     | 0.0     | 0.0     | 0.0     | -2.788812E+05 | -2.788812E+05       | -2.788812E+05 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -2.788812E+05 | -2.788812E+05       | -2.788812E+05 |                  |
| 0           | 23                               | 0.0     | 0.0     | 0.0     | 0.0     | 5.447155E+04  | 5.447155E+04        | 5.447155E+04  |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | 5.447155E+04  | 5.447155E+04        | 5.447155E+04  |                  |
| 0           | 24                               | 0.0     | 0.0     | 0.0     | 0.0     | 7.126953E+04  | 7.126953E+04        | 7.126953E+04  |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | 7.126953E+04  | 7.126953E+04        | 7.126953E+04  |                  |
| 0           | 25                               | 0.0     | 0.0     | 0.0     | 0.0     | -5.633950E+04 | -5.633950E+04       | -5.633950E+04 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -5.633950E+04 | -5.633950E+04       | -5.633950E+04 |                  |
| 0           | 26                               | 0.0     | 0.0     | 0.0     | 0.0     | -4.298890E+04 | -4.298890E+04       | -4.298890E+04 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -4.298890E+04 | -4.298890E+04       | -4.298890E+04 |                  |
| 0           | 27                               | 0.0     | 0.0     | 0.0     | 0.0     | 2.617770E+05  | 2.617770E+05        | 2.617770E+05  |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | 2.617770E+05  | 2.617770E+05        | 2.617770E+05  |                  |
| 0           | 28                               | 0.0     | 0.0     | 0.0     | 0.0     | -1.028712E+06 | -1.028712E+06       | -1.028712E+06 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -1.028712E+06 | -1.028712E+06       | -1.028712E+06 |                  |
| 0           | 29                               | 0.0     | 0.0     | 0.0     | 0.0     | -5.089336E+05 | -5.089336E+05       | -5.089336E+05 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -5.089336E+05 | -5.089336E+05       | -5.089336E+05 |                  |
| 0           | 30                               | 0.0     | 0.0     | 0.0     | 0.0     | -2.234615E+05 | -2.234615E+05       | -2.234615E+05 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -2.234615E+05 | -2.234615E+05       | -2.234615E+05 |                  |
| 0           | 31                               | 0.0     | 0.0     | 0.0     | 0.0     | -1.196898E+05 | -1.196898E+05       | -1.196898E+05 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -1.196898E+05 | -1.196898E+05       | -1.196898E+05 |                  |
| 0           | 32                               | 0.0     | 0.0     | 0.0     | 0.0     | -8.609246E+04 | -8.609246E+04       | -8.609246E+04 |                  |
|             |                                  | 0.0     | 0.0     | 0.0     | 0.0     | -8.609246E+04 | -8.609246E+04       | -8.609246E+04 |                  |
| 1           | BATSAT STRUCTURE                 |         |         |         |         | MAY 5, 1993   | MSC/NASTRAN 9/ 4/91 | PAGE 52       |                  |
|             | SIDE VIEW PANEL STRESSES (MOD14) |         |         |         |         |               |                     |               |                  |

0 SUBCASE 1

| ELEMENT ID. |    | SA1 SB1 | SA2 SB2 | SA3 SB3 | SA4 SB4 | AXIAL STRESS  | SA-MAX SB-MAX | SA-MIN SB-MIN | M.S.-T<br>M.S.-C |
|-------------|----|---------|---------|---------|---------|---------------|---------------|---------------|------------------|
| 0           | 33 | 0.0     | 0.0     | 0.0     | 0.0     | 1.784623E+04  | 1.784623E+04  | 1.784623E+04  |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | 1.784623E+04  | 1.784623E+04  | 1.784623E+04  |                  |
| 0           | 34 | 0.0     | 0.0     | 0.0     | 0.0     | -2.783613E+04 | -2.783613E+04 | -2.783613E+04 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -2.783613E+04 | -2.783613E+04 | -2.783613E+04 |                  |
| 0           | 35 | 0.0     | 0.0     | 0.0     | 0.0     | -1.062294E+06 | -1.062294E+06 | -1.062294E+06 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -1.062294E+06 | -1.062294E+06 | -1.062294E+06 |                  |
| 0           | 36 | 0.0     | 0.0     | 0.0     | 0.0     | -3.508443E+04 | -3.508443E+04 | -3.508443E+04 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -3.508443E+04 | -3.508443E+04 | -3.508443E+04 |                  |
| 0           | 37 | 0.0     | 0.0     | 0.0     | 0.0     | -1.004737E+06 | -1.004737E+06 | -1.004737E+06 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -1.004737E+06 | -1.004737E+06 | -1.004737E+06 |                  |
| 0           | 38 | 0.0     | 0.0     | 0.0     | 0.0     | 1.647573E+05  | 1.647573E+05  | 1.647573E+05  |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | 1.647573E+05  | 1.647573E+05  | 1.647573E+05  |                  |
| 0           | 39 | 0.0     | 0.0     | 0.0     | 0.0     | -5.196439E+04 | -5.196439E+04 | -5.196439E+04 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -5.196439E+04 | -5.196439E+04 | -5.196439E+04 |                  |
| 0           | 40 | 0.0     | 0.0     | 0.0     | 0.0     | -1.387357E+05 | -1.387357E+05 | -1.387357E+05 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -1.387357E+05 | -1.387357E+05 | -1.387357E+05 |                  |
| 0           | 41 | 0.0     | 0.0     | 0.0     | 0.0     | -1.068905E+05 | -1.068905E+05 | -1.068905E+05 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -1.068905E+05 | -1.068905E+05 | -1.068905E+05 |                  |
| 0           | 42 | 0.0     | 0.0     | 0.0     | 0.0     | -7.199831E+04 | -7.199831E+04 | -7.199831E+04 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -7.199831E+04 | -7.199831E+04 | -7.199831E+04 |                  |
| 0           | 43 | 0.0     | 0.0     | 0.0     | 0.0     | -7.416995E+04 | -7.416995E+04 | -7.416995E+04 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -7.416995E+04 | -7.416995E+04 | -7.416995E+04 |                  |
| 0           | 44 | 0.0     | 0.0     | 0.0     | 0.0     | 8.767053E+04  | 8.767053E+04  | 8.767053E+04  |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | 8.767053E+04  | 8.767053E+04  | 8.767053E+04  |                  |
| 0           | 45 | 0.0     | 0.0     | 0.0     | 0.0     | -3.338393E+04 | -3.338393E+04 | -3.338393E+04 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -3.338393E+04 | -3.338393E+04 | -3.338393E+04 |                  |
| 0           | 46 | 0.0     | 0.0     | 0.0     | 0.0     | -4.250688E+05 | -4.250688E+05 | -4.250688E+05 |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | -4.250688E+05 | -4.250688E+05 | -4.250688E+05 |                  |
| 0           | 47 | 0.0     | 0.0     | 0.0     | 0.0     | 7.418273E+04  | 7.418273E+04  | 7.418273E+04  |                  |
|             |    | 0.0     | 0.0     | 0.0     | 0.0     | 7.418273E+04  | 7.418273E+04  | 7.418273E+04  |                  |

P L O T T E R   D A T A

THE FOLLOWING PLOTS ARE FOR A NASTPLT PLOTTER

PAPER SIZE = 20.0 X 20.0,   PAPER TYPE = VELLUM

PEN 1 - SIZE 1, BLACK  
PEN 2 - SIZE 1, BLACK  
PEN 3 - SIZE 1, BLACK  
PEN 4 - SIZE 1, BLACK

E N G I N E E R I N G   D A T A

ORTHOGRAPHIC PROJECTION  
ROTATIONS (DEGREES) - GAMMA =   0.00, BETA =   0.00, ALPHA =   0.00, AXES = -Y,+X,+Z, SYMMETRIC  
SCALE (OBJECT-TO-PLOT SIZE) = 2.512692E+01

ORIGIN        1        -   X0 = -9.280000E+00, Y0 = -2.330045E+00        (INCHES)

L I S T   O F   P L O T S

PLOT    2    STATIC STRESS        1 - SUBCASE        500 - LOAD

C O N T O U R   P L O T T I N G   D A T A

ABOVE PLOT IS A CONTOUR PLOT OF STRESS, MAJOR-PR        MIN = -5.361738E+04        MAX =   8.097764E+05  
THE CONTOUR VALUES ARE CALCULATED AT FIBER DISTANCE MAX - Z1,Z2

TABLE OF   P L O T T I N G   S Y M B O L S

| SYMBOL | VALUE         | SYMBOL | VALUE | SYMBOL | VALUE | SYMBOL | VALUE | SYMBOL | VALUE |
|--------|---------------|--------|-------|--------|-------|--------|-------|--------|-------|
| 1      | -5.361738E+04 |        |       |        |       |        |       |        |       |
| 2      | 1.190614E+05  |        |       |        |       |        |       |        |       |
| 3      | 2.917401E+05  |        |       |        |       |        |       |        |       |
| 4      | 4.644189E+05  |        |       |        |       |        |       |        |       |
| 5      | 6.370976E+05  |        |       |        |       |        |       |        |       |
| 6      | 8.097764E+05  |        |       |        |       |        |       |        |       |

\* \* \* END OF JOB \* \* \*

## **Appendix A, cont.**

### **NASTRAN Frequency Analysis**



```

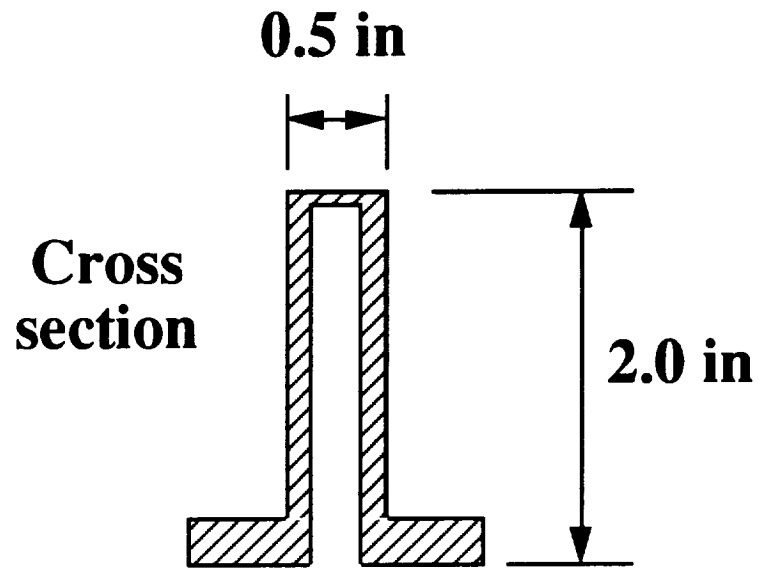
NASTRAN
ASSIGN MASTER='MOD14.MASTER'
RESTART, VERSION=1
ID NORMAL MODES
SOL 103
TIME 3
CEND
TITLE=ASE274 - MODEL 1
SUBTITLE=MODEL 1 STATIC
DISP=ALL
LABEL = NORMAL MODES ANALYSIS
METHOD=4
LOAD=500
OLOAD=ALL
SUBCASE 1
SPC=102
OUTPUT(PLOT)
PLOTTER NAST
SET 1=QUAD4,TRIA3
AXES MY,X,Z
VIEW 0.,0.,0.
FIND SCALE,ORIGIN 1,SET 1
PLOT SET 1,ORIGIN 1,LABEL BOTH
PLOT STATIC DEFORMATION 0, SET 1, ORIGIN 1, LABELBOTH
BEGIN BULK
$L= .1687          r= .26  d= .05 radius =0.01
$1.....2.....3.....4.....5.....6.....7.....8.....9.....10
$
EIGRL    4          -0.1          4          0
ENDDATA

```



## Appendix B

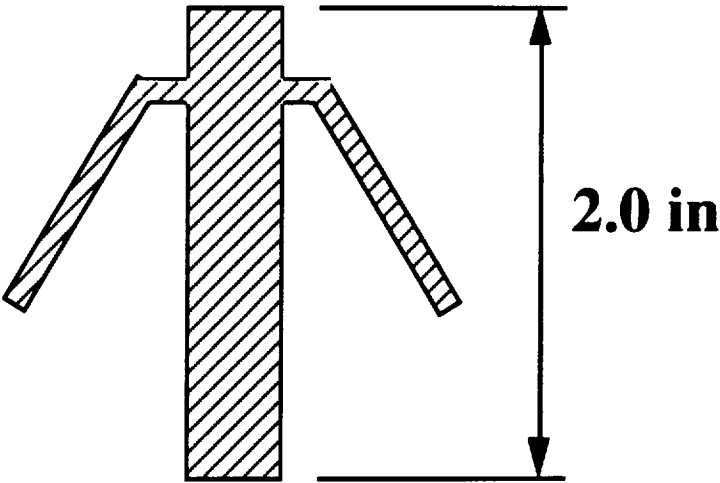
### BATSAT Antennae



### Ka Band Antenna

**BATSAT Antennae (Cont.)**

**Cross  
section**



**S Band Antenna**

## Appendix C

### BATSAT Power Sizing

| Instrument in Use |                |            |
|-------------------|----------------|------------|
|                   | Equipment      | Power Req. |
| on                | Ka Transmitter | 1.5 W      |
| on                | X Transmitter  | 1.5 W      |
| off               | Ku Transmitter | 5.1 W      |
| off               | S Transmitter  | 1.5 W      |
| on                | Heaters        | 2.0 W      |
| on                | Command        | 2.1 W      |
| Total Power=      |                | 8.6 W      |

| S i      | Solar Cell Info |             |
|----------|-----------------|-------------|
|          | Si              | GaAs        |
| Po       | 190.0 W/m2      | 244.0 W/m2  |
| Id       | 0.77            | 0.77        |
| LdegFact | 3.75%           | 2.75%       |
| Mass/m^2 | 2.800 kg/m2     | 1.600 kg/m2 |
| Cost/m^2 | \$83.19         | \$415.00    |

#### Power Design Parameters

|                     |                                       |
|---------------------|---------------------------------------|
| Life= 10.0 yrs      | Satellite Lifetime                    |
| Theta = 0.0 °       | Array incidence angle                 |
| Period = 110.51 min | Orbital Period                        |
| Pe= 8.6 W/m2        | Eclipse Power (from equipment choice) |
| te= 35.80 min       | Eclipse Duration                      |
| xe= 0.65            | Array-Batt.-Load efficiency           |
| Pd= 8.6 W/m2        | Daylight Power                        |
| td= 74.71 min       | Day duration                          |
| xd= 0.9             | Source-Load efficiency                |
| Cd= 0.1             | Battery Depth of Discharge            |
| Vd= 27.5            | Battery discharge voltage             |
| N= 1                | Number of batteries                   |
| Po = 190.0 W/m2     | From Array Choice                     |
| Id = 0.77           | From Array Choice                     |
| LdegFact= 3.75%     | From Array Choice                     |

#### Computed Solar Paramters

|                  |                                |
|------------------|--------------------------------|
| Psa= 15.8 W/m2   | Total daylight collected power |
| Pbol= 146.3 W/m2 | Power beginning of life        |
| Peol= 99.8 W/m2  | Power ending of life           |

|                     |   |
|---------------------|---|
| Asa= 0.174 m^2      | Total Estimated array Area + 10%,unadjusted for shape |
| Est Mass = 1.952 kg | Adjusted for shape                                    |
| Est Cost = \$57.99  | Total Estimated Cost in thousands, adjusted for shape |
| Cr= 2.06 A-hrs      | Battery Capacity in A-hrs                             |

#### Spacecraft Sizing

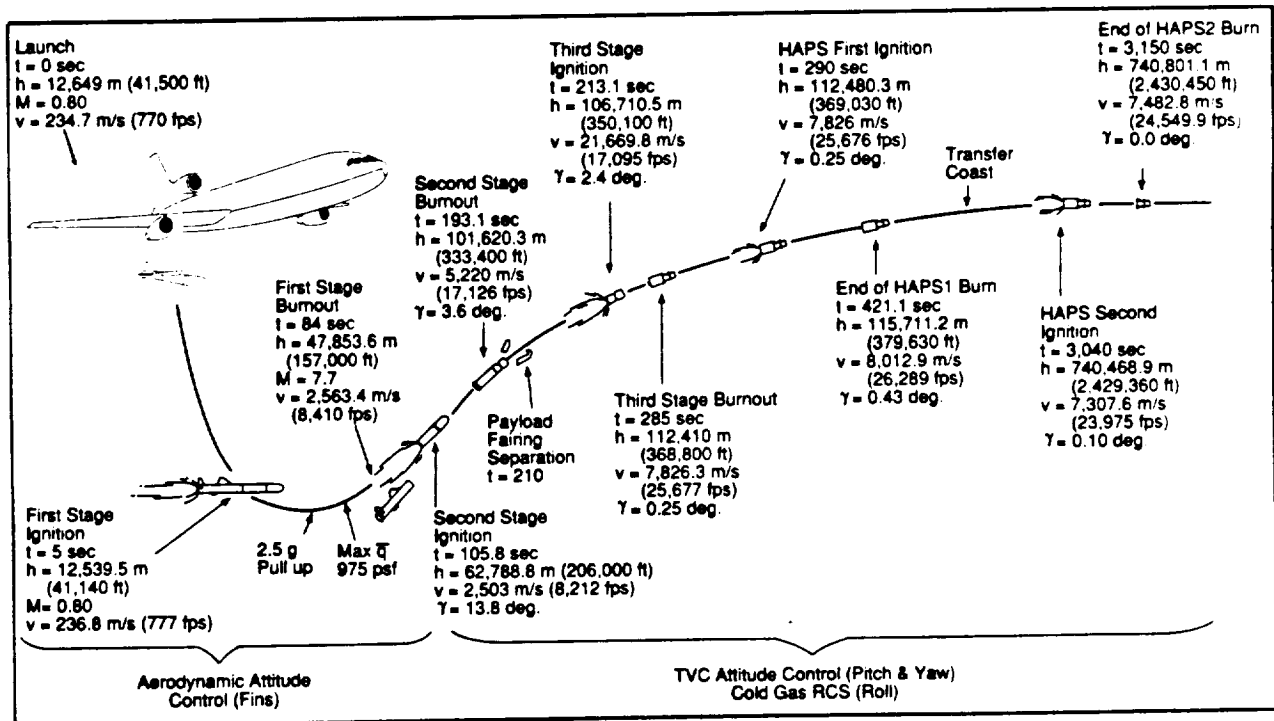
|           |               |
|-----------|---------------|
| Shape:    | Grav-Gradient |
| Min Area: | 0.547 m^2     |
| Radius:   | 0.25 m        |
| Height:   | 0.35 m        |

|           |           |
|-----------|-----------|
| Shape:    | Spherical |
| Min Area: | 0.697 m^2 |
| Radius:   | 0.24 m    |
| Height:   | n/a       |

## Appendix D

### Pegasus Mission Timeline With HAPS Booster

[Source: Pegasus User's Guide]



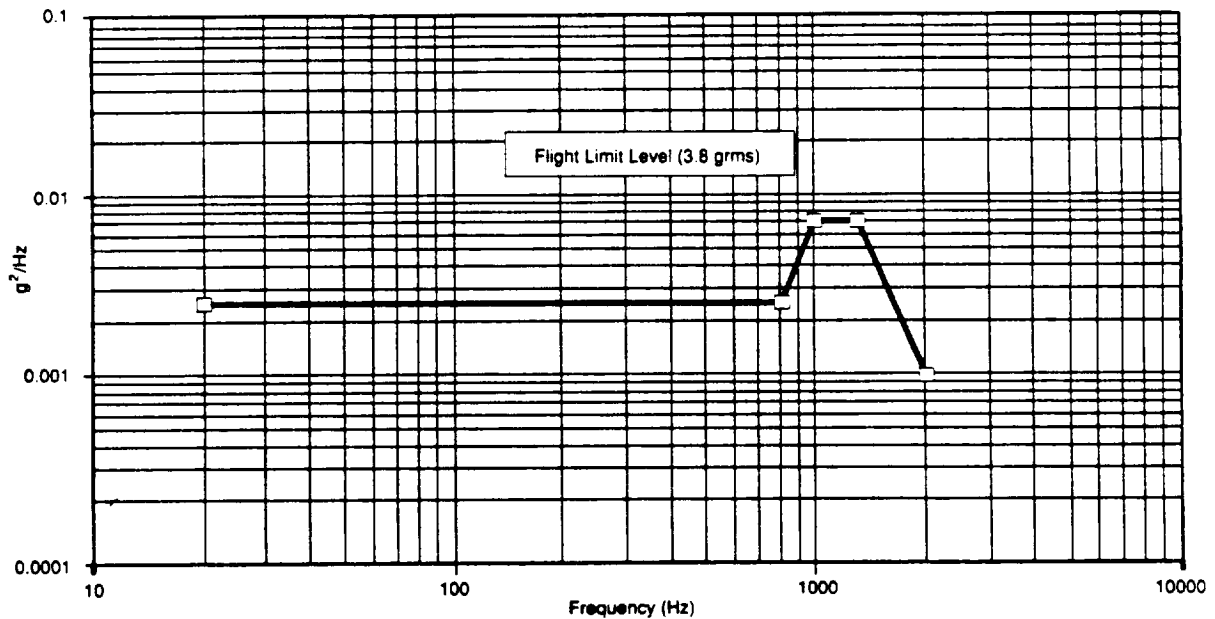
## Pegasus Launch Environment

[Source: Pegasus User's Guide]

### Acceleration Environment

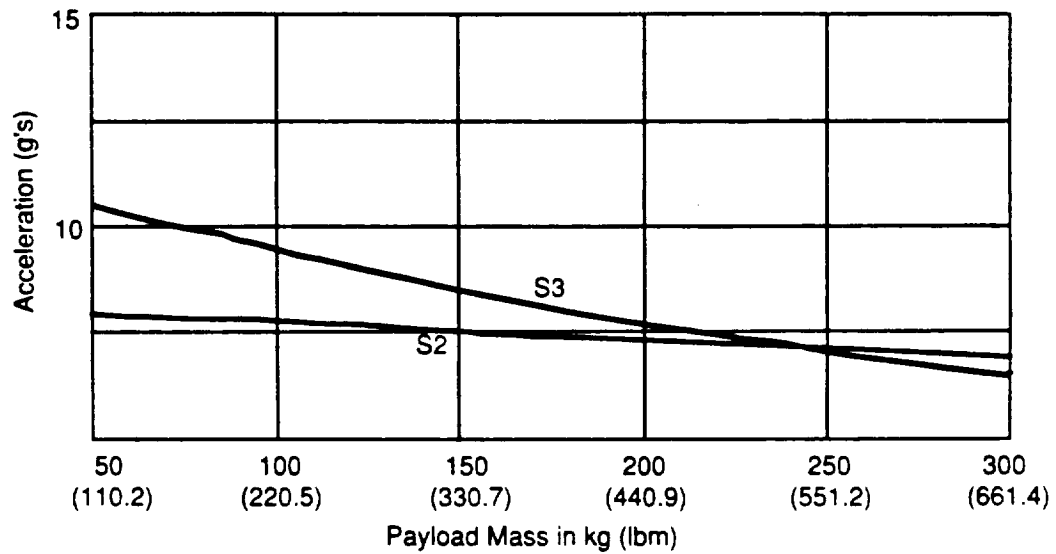
| Type   |        | Linear Acceleration (g's)          |        |                      |
|--|--------|------------------------------------|--------|----------------------|
|  |        | x                                  | y      | z                    |
| Ground Operations  |        | +/-0.5                             | +/-0.5 | + 1.5                |
| Captive Carry Flight/Taxi <sup>1</sup>   | Case 1 | +/-1.0                             | 0      | + 2.2/-1.0           |
|  | Case 2 | 0                                  | +/-0.3 | + 2.2                |
|  | Case 3 | 0                                  | +/-0.4 | + 1.0                |
| Abort Landing  |        | +/-0.6                             | +/-0.6 | + 2.7/-0.1           |
| Launch/Drop  |        | 0                                  | 0      | Payload<br>Dependent |
| Aerodynamic Pull-up  |        | -4.0                               | +/-0.5 | +2.85                |
| First Stage Burnout  |        | -7.5                               | +/-0.2 | +/-0.2               |
| Second and Third Stage Burnout   |        | Payload Dependent (See Figure 4.1) |        |                      |
| Note 1: Payload must meet each of these case requirements individually to satisfy NASA-Dryden B-52 utilization constraints |        |                                    |        |                      |

### Payload Vibration Environment

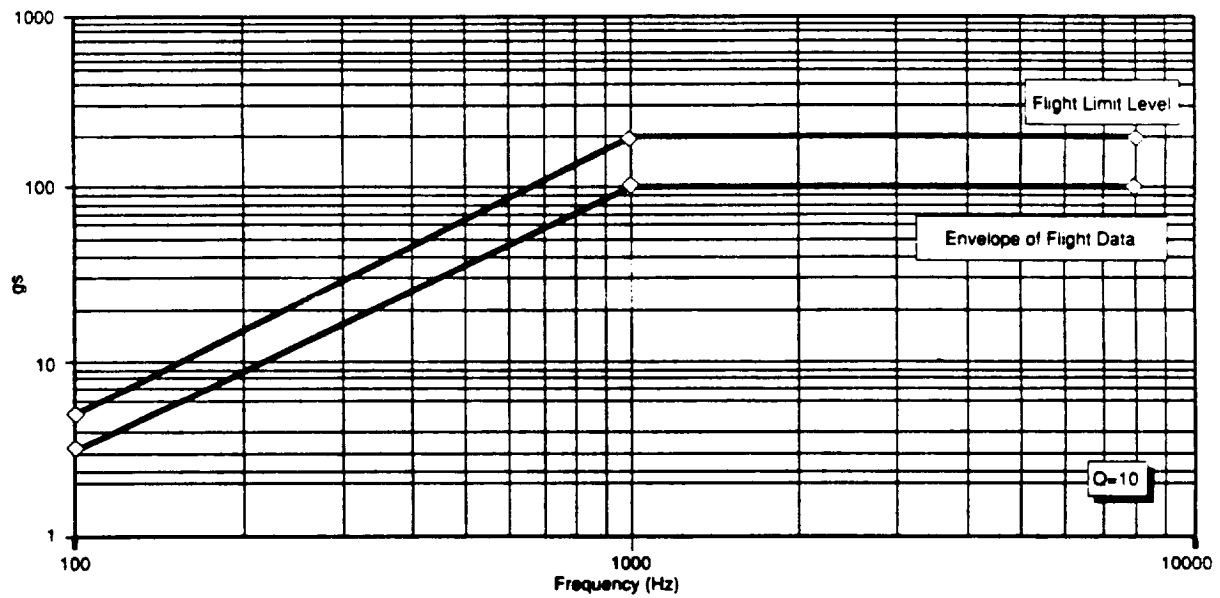


## Pegasus Launch Environment cont.

### Payload Maximum Axial Acceleration



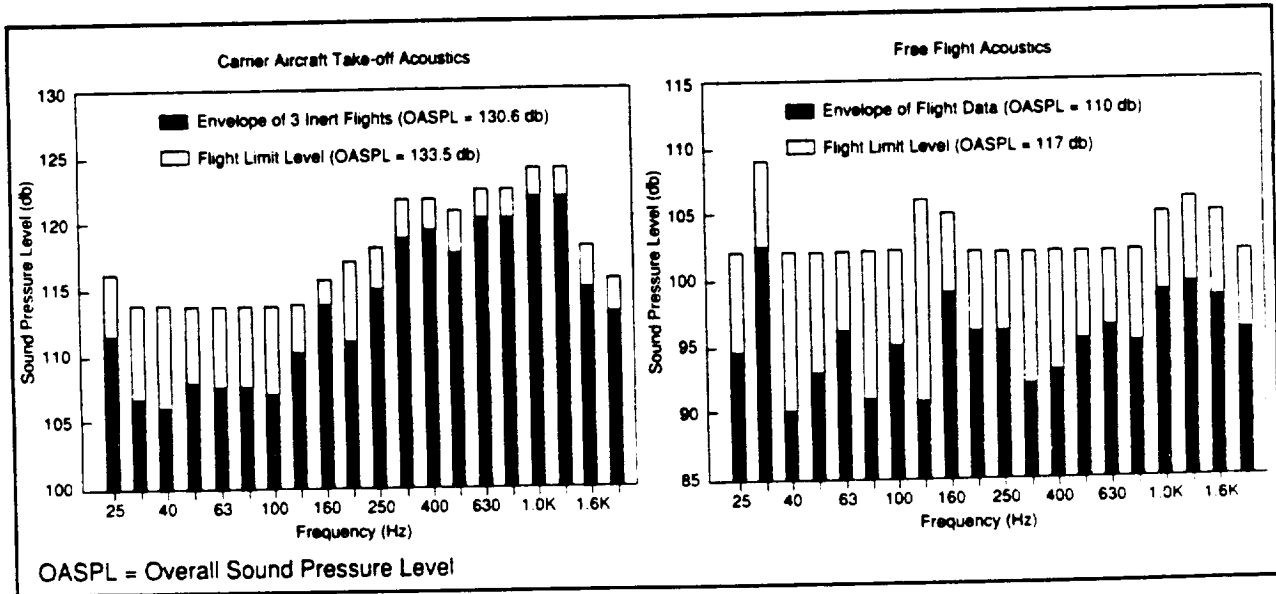
### Payload Shock Environment





## Pegasus Launch Environment cont.

### Payload Acoustic Environment





# ***Mockingbird Designs***

*Excellence in Engineering*